TEST AND EVALUATION OF A VTPR RETRIEVAL SYSTEM FROM CLEAR-COLUMN NOAA 2 RADIANCES

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THESIS

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VTPR RETRIEVAL SYSTEM FROM
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by

Harry Milton Dyck Jr.

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TABLE OF SYMBOLS AND ABBREVIATIONS

$B_i[T(P)]$	Planck radiance function for temperature T at pressure level p and channel i
$\bar{B}_i(K)$	Layer mean Planck function for layer K, in channel i
$B^{(n)}[\bar{\nu},T(J)]$	Weighted mean Planck function at iteration n and for level J, using the normalized wave number $\bar{\nu}$
CLRAD	National Environmental Satellite Service (NESS) program for obtaining clear-column radiances
ITPR	Infrared Temperature Profile Radiometer
J	The subscript used to denote the levels in a 100 level atmosphere where $$J = 1 + 99\left[\frac{P^{2/7} - (0.01)^{2/7}}{(1000)^{2/7} - (0.01)^{2/7}}\right]$$
K	The subscript used to denote the layers in a 33 layer atmosphere
mb	millibar
NASA	National Aeronautics and Space Administration
NESS	National Environmental Satellite Service
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NTP	Normal Temperature and Pressure conditions
ν_i	Wave number at the center of channel i
$\bar{\nu}$	Normalized wave number, $\tilde{\nu} \doteq 700\ cm^{-1}$ and is a decreasing function of pressure
P(J)	Pressure at level J
P_s	Pressure at the surface of the earth (1000 mb)
RTE	Radiative transfer equation

SIRS	Satellite Infrared Spectrometer
SR	Scanning Radiometer
T[P(J)]	Temperature of the atmosphere at the pressure level P(J)
$\tau_i(J)$	Atmospheric transmittance at level J, in channel i
τ[X(J)]	Atmospheric transmittance at level J from constituent X
μm	micrometers = 10^{-6} meters
VTPR	Vertical Temperature Profile Radiometer
*	Fortran symbol for multiplication used, if necessary, for clarification

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It is appropriate here to recognize the generous support of Dr. L. M. McMillin and Dr. M. P. Weinreb who provided not only operational programs which were consistent with the instrument in use, but also, when requested, explained the physical rationale of such programs in connection with retrieval procedures at NESS.

I. INTRODUCTION

The quantitative measurement of temperatures at known pressure levels in the atmosphere is fundamental to present day weather analysis and forecasting. Until the launch of the Nimbus 3 satellite with its Satellite Infrared Spectrometer (SIRS) in April 1969, free air temperature soundings were obtained entirely from balloons, aircraft, and rockets. Since these sources were readily available only from populous land areas and a few ships, large areas of the world were without any reports. World-wide distribution of temperature sounding data was made possible by the use of satellites. The retrieval of a temperature profile by remote-sensing satellite measurements was first suggested by Kaplan (1959), and has been the object of numerous research studies.

The Nimbus 3 and Nimbus 4 satellites were equipped with SIRS-A and SIRS-B respectively. These first generation SIRS instruments, SIRS-A with a vertical scan, and SIRS-B with an additional side scan, measured monochromatic radiances in seven narrow regions or channels of the 15 μm band of carbon dioxide, and one in the window region of water vapor centered at 899 cm^{-1}. Figure 1 (from Gelman et al. 1972) shows the weighting functions $d\tau_i/d(\ln P)$, after Smith et al. (1972), of the radiometric emitting channels of the SIRS-B instruments. A peak in $d\tau_i/dx$ relative to the $\ln P$ axis depicts the layer in the vertical contributing the maximum radiance to the

satellite channel sensor. These radiances could then be related to temperature profiles through the Radiative Transfer Equation (RTE)

$$I_i = B_i[T(P_s)]\ \tau_i(P_s) + \int_{P_s}^{P_o} B_i[T(P)]\ \frac{d\tau_i}{dP}\, dP \ . \qquad (1)$$

Here, I_i is the spectral radiance in channel i (i=1,2,...,8), $B_i[T(P)]$ is the well-known Planck function for wave number ν_i and at temperature T(P), $\tau_i(P)$ is the atmospheric transmittance averaged over wave number i (where i signifies the channel number centered at ν_i), and P is the pressure-level for which $\tau_i(P)$ has been computed.

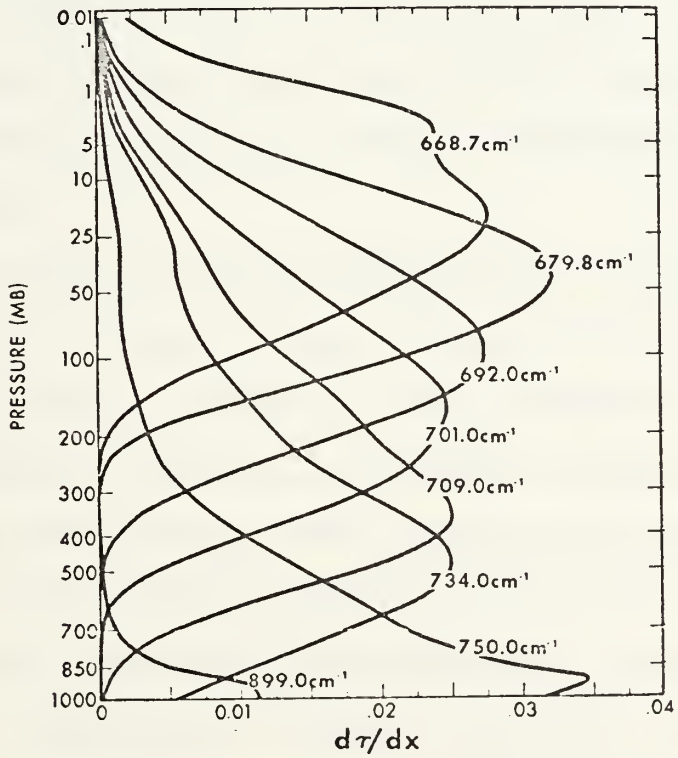


FIGURE 1. Derivative of transmittance (τ) with respect to $x(P) = P^{2/7}$ for SIRS-B (after Gelman et al. 1972)

Retrieval of temperature profiles from the SIRS-B radiometer was continued in systematic fashion by the National Environmental Satellite Service (NESS) until the radiometer output was considered non-usable on 8 April 1971. The number of retrievable satellite soundings collected during 1969-71 was insufficient to make a marked impact on the analysis problem over the oceans.

Anticipating an increased demand for quantitative weather observations from orbiting satellites, the National Oceanic and Atmospheric Administration (NOAA) in conjunction with the National Aeronautics and Space Administration (NASA), developed a second generation set of remote-sensing radiometers, improved over the SIRS-type, that would provide twice daily coverage of most of the globe and a higher resolution at individual scan spots.

As a result of these developments, the first of the new instruments was the Infrared Temperature Profile Radiometer (ITPR) as used on Nimbus 5. This radiometer carried four carbon dioxide channels, two window channels at 4.3 μm and 11.5 μm, respectively, and a water vapor channel near 20 μm. In 1972, NASA launched the NOAA-2 satellite, which carried aloft a new remote-sounding radiometer for which the ITPR had been a prototype. The new instrument, the Vertical Temperature Profile Radiometer (VTPR), had been still further improved over the ITPR in its angular-array scanning technique. The VTPR carried six carbon dioxide channels, a window channel,

and a water vapor channel. Observations made at scan spot arrays in channels 1,2,...,8 made it possible to systematically retrieve clear-column radiances at a higher resolution than before. The new instrument was designed to provide two temperature profiles per grid point per day on a 400 kilometer spacing over the oceans, or a global total of 6000 temperature profiles per day. An actual yield of 72%, or about 4000 profiles per day has been realized [Jastrow and Halem (1973)]. The use of these VTPR clear-column radiances from the NOAA 2 satellite and the temperature retrieval system described by McMillan et al. (1973) was the basis for a thesis by Moran (1974). The basic differences between the Moran study and previous work by Smith et al. (1972) was the use, by Moran, of standard atmospheric carbon dioxide transmittances with no interactive effects on the channel 1,2,...,6 transmittances from the other atmospheric constituents. Moran also computed radiances by the use of a 17-layer quadrature scheme for integration of Eq. 1 rather than by means of the more usual 100-level atmosphere. This was done in order to attempt to reduce the trunction error involved with uncertainties in the integration of the function $B_i[T(P)]d\tau_i/dp$ when a relatively crude model for $\tau_i(P)$ was utilized.

The first objective of the present thesis was to improve upon the Moran retrieval technique by incorporating recently updated state-of-the-art methods [Fritz et al (1972)] for computing atmospheric transmittances, including the combined

effects of water vapor, ozone, and carbon dioxide in each channel, as well as their vertical path dependencies on pressure and temperature. It was also necessary to correct these transmittances in each channel for the applicable zenith angles of the clear-column spot. For this purpose, a special data set for March 1973, including the tuned transmittance coefficients for the period, coupled with the first-guess temperature and humidity profiles, was acquired from NESS.

A second and equally important objective was to test the final temperature retrievals by comparison with radiosondes at island and coastal stations matching the VTPR scan spots in both time and spatial location. The retrieved profiles were compared at each of the 15 standard pressure levels (Table 3) with the matching radiosondes and were analyzed both by latitude and by pressure level.

The retrieval system used here has the feature of integrating Eq. 1 over 33 atmospheric layers at each clear-column radiance scan spot. This system was incorporated in order to minimize the truncation error in the quadrature scheme applied to the function $B_i d\tau_i/dp$ which appears in the RTE (Eq. 1). The improved accuracy in the determination of the temperature profile using this method is one of the main thrusts of this thesis.

II. SATELLITE DATA

The NOAA series of satellites are modifications of the earlier Environmental Science Service Administration (ESSA) satellites. The major change was the elimination of all vidicon camera systems in favor of radiation-sensing instruments, and in particular the inclusion of the vertical temperature profile radiometer (VTPR).

A. NOAA 2 DESCRIPTION

The NOAA 2 satellite orbits the earth at an altitude of 1464 kilometers once during each 115 minutes. Figure 2 illustrates the projection of seven orbits onto the earth. The solid lines indicate the north-to-south or "descending" portions of the orbits, which occur over the sunlit hemisphere; dashed lines are nighttime "ascending" portions of the same orbits. Equatorial crossings occur at 0900 (descending) and 2100 (ascending) local solar time.

The VTPR instrument scans perpendicularly relative to the subsatellite track from left to right, when viewed downtrack, in 23 individual non-overlapping steps covering ±30.3 degrees from local nadir. The instrument observes each spot in eight spectral intervals or channels through the use of the automatic optical filter selector equipment of the VTPR. Six of the channels are located in the 15 μm band of carbon dioxide, one in the 19 μm region of the rotational band of water vapor, and

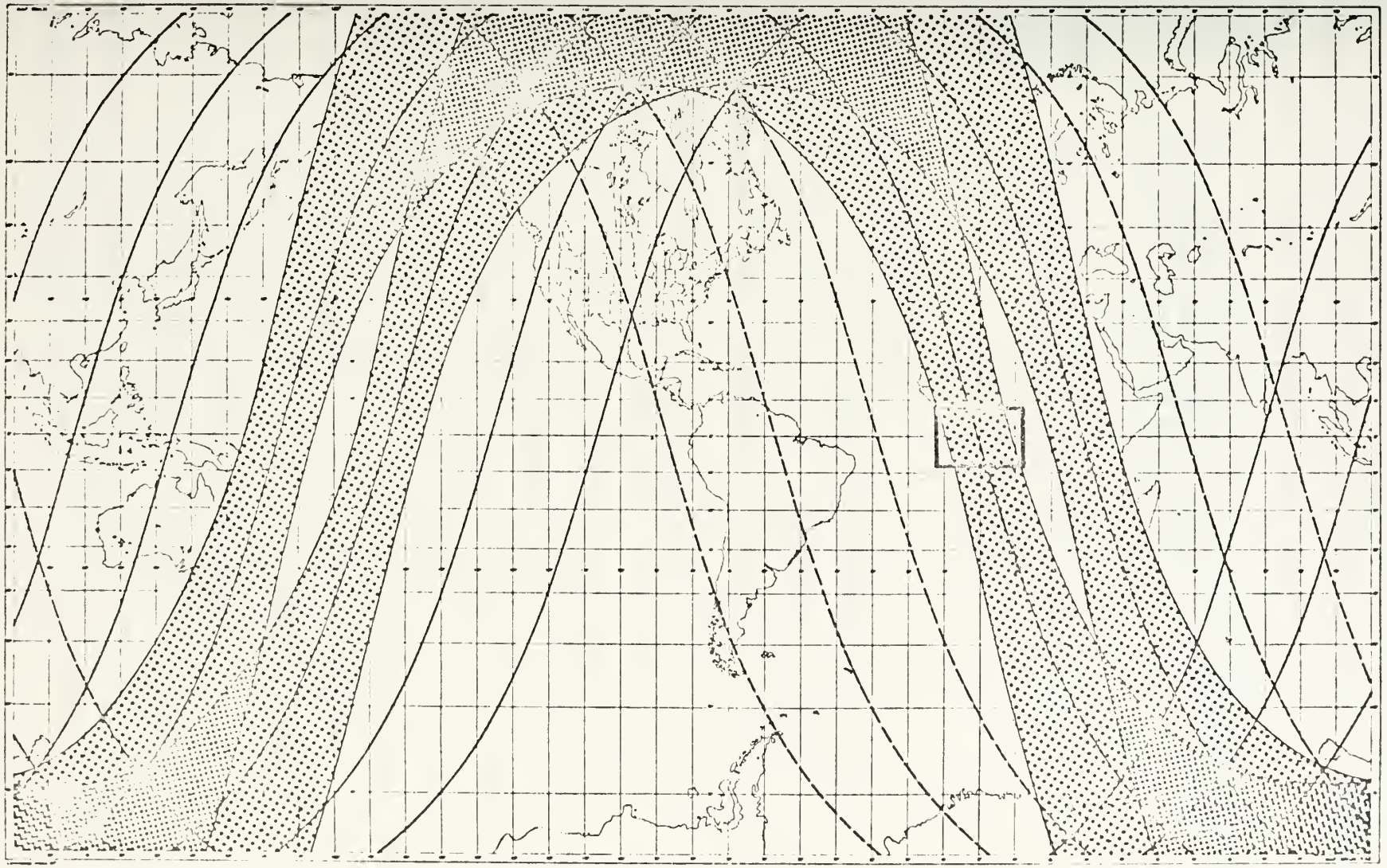


Figure 2 — Satellite tracks for NOAA 2 VTPR coverage

one in the 12 μm atmospheric window (see Table 1). After the entire set of 8 spectral measurements has been obtained, the scanning mirror rotates to the next spot.

Table 1. VTPR channel designators and centroid wave numbers for filter set four of NOAA 2 VTPR instrument number 1 (used in March 1973).

CHANNEL	1	2	3	4	5	6	7	8
WAVE NO. (cm^{-1})	668.5	677.5	695.7	707.2	724.7	747.5	534.5	835.1

B. CLEAR-COLUMN PROCEDURE

In order to obtain an accurate temperature retrieval, the "raw" radiances, that is the radiances measured at the VTPR instrument, must be adjusted to eliminate the effects of any clouds that may be located in the field of view. Smith (1970) and others introduced cloud layer models wherein the extent and thickness of cloud layers which would give the radiance as sensed at the satellite are mathematically introduced into the temperature profile calculation. However, the results in the neighborhood of a single scan spot tend to result in non-unique cloud heights and amounts which causes uncertainty in the deduced clear-column radiances. The method described below was later developed by Smith (1971) in order to eliminate these uncertainties.

The National Environmental Satellite Service (NESS) eliminates cloud contamination through the use of a conversion program called CLRAD, applied to a large array of contiguous

raw radiance spots. Sets of eight scan lines, containing 23 scan spots are divided into 3 subarrays or boxes of 8 by 8, 8 by 7, and 8 by 8 scan spots as shown in Figure 3. Observations of raw VTPR radiances are made in each of the eight channels and at each scan spot. Figure 4 shows the lateral scan geometry along each scan line, where spot 5, spot 12, and spot 19 in line 4, are the center of box left, box center and box right, respectively. Each box-center is denoted by an X in Figure 3. At these locations it is necessary to determine the exact zenith angles to the sensor aboard the satellite using the following relationship

$$\mathrm{SIN}(Z_n) = \mathrm{SIN}(N_n)\ \frac{a+H}{2} \qquad (2)$$

Here Z_n is the zenith angle at scan spot n (n = 5,12,19). N_n is the nadir angle at the same spots, a is the constant 6370 km (earth's radius), and H is the altitude of the satellite (mean value of 1460 km). The mean zenith angle at spot 12 is 0°, while at spots 5 and 19 it is 23°47' left and right of center respectively.

In addition to the VTPR radiances, measurements in a Window-channel Scanning Radiometer (SR), sensing in 10.5 to 12.5 μm, permits determination of the sea surface temperatures at each of the scan spots. McMillin et al. (p 25-33, 1973) outline a process of extrapolation of raw-radiance to clear column radiance within localized sub-areas about the scan

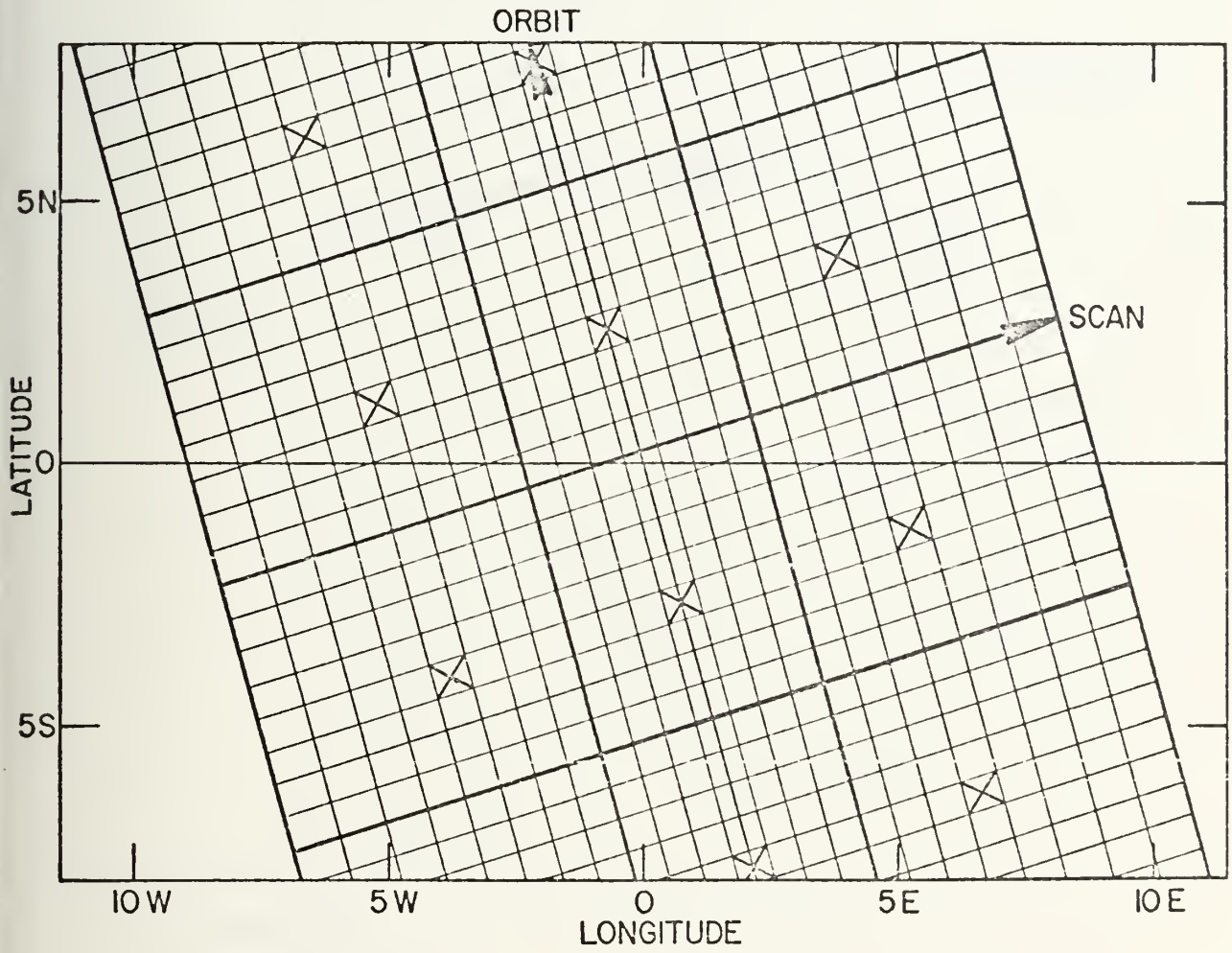
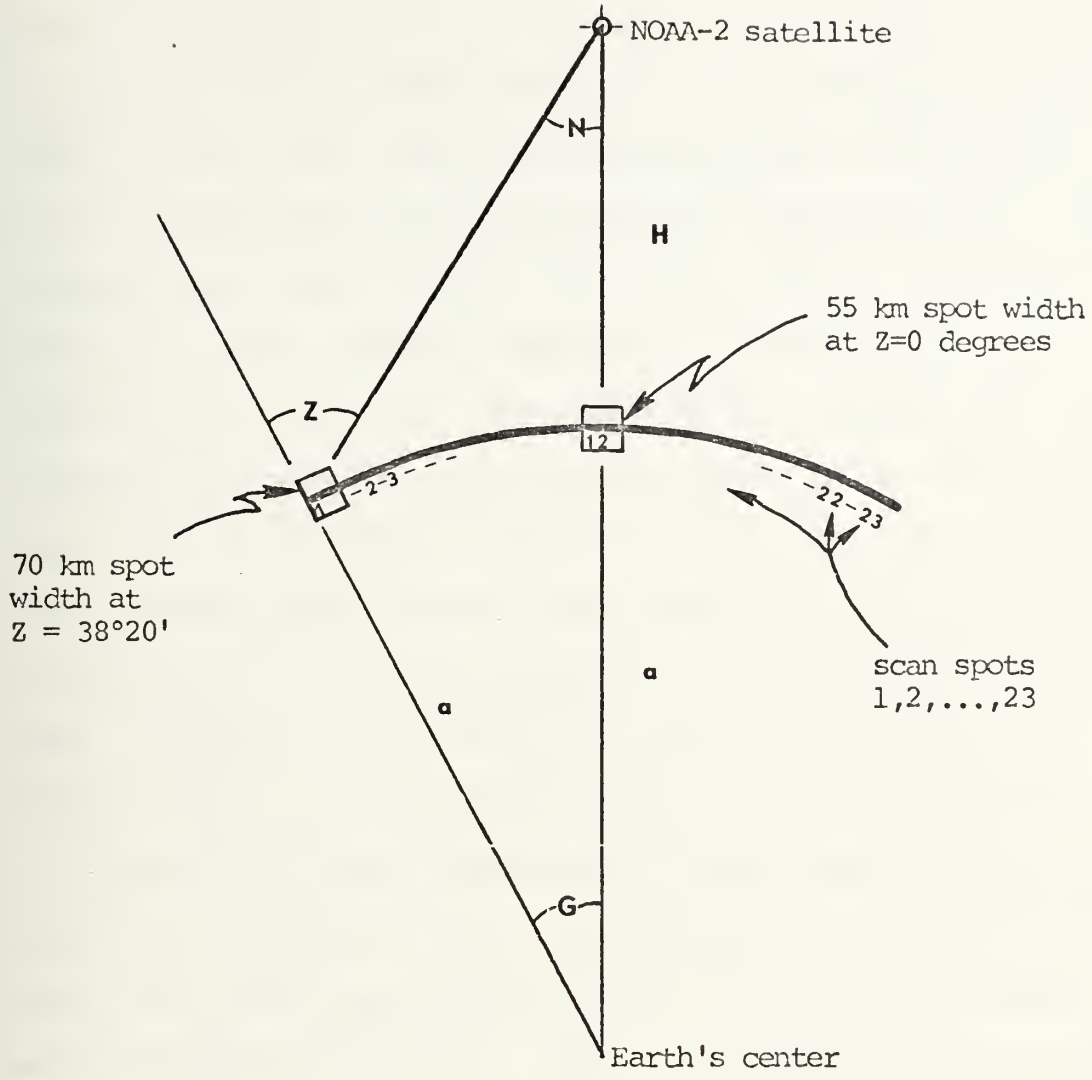


Figure 3 — VTPR scan pattern and data analysis array



N = Nadir angle

Z = Zenith angle

G = Geocentric angle

a = Earth's radius (6370 km)

H = Satellite altitude (mean = 1460 km)

Figure 4. NOAA-2 VTPR lateral scan geometry at raw radiance spots

spots. The specifics of the clear radiance conversion method involves: (1) the specifications of a reasonably accurate value of the first guess temperature profile T(P) to 10 mb, (2) an estimation of the water vapor transmittances in the window channel derived from the T(P), and (3) the determination of the sea surface temperature derived from the SR. The value of the clear-column window channel radiance can then be computed and compared with the observed window channel radiance. If the observed "raw" radiance is equal to or greater than the computed radiance, the sounding is considered to be cloud free. If the computed radiance is greater than the "raw" radiance, the sounding is considered to be cloud contaminated and the extrapolation process is necessary.

To facilitate the extraction of the clear-column radiance set, "raw" radiance values from adjacent spot pairs (spots 1 and 2 with their associated $I_1(\nu)$ and $I_2(\nu)$ for example) are extrapolated to $I_{clear}(\nu)$. This can be done if the cloud amounts vary linearly in the field of view and share approximately the same cloud top level. Figure 5 shows the patterns used by NESS for pair comparisons. Each 8 by 8 box, so analyzed, will contain 49 scan spots, which can be compared with four adjacent spots for a total possible yield of 196 values of clear-column radiance $I_{clear}(\nu_i)$. Here i denotes all channels other than the window channel since the window channel gives rise only to a possible 49 clear-column estimates. A proportionately smaller number of both radiance sets are found in the 8 by 7 box. If a suitable number of

the scan spots are capable of giving four adjacent clear-column values without excessive variances, all resulting values are usable in obtaining the weighted clear-column radiance in the respective channels.

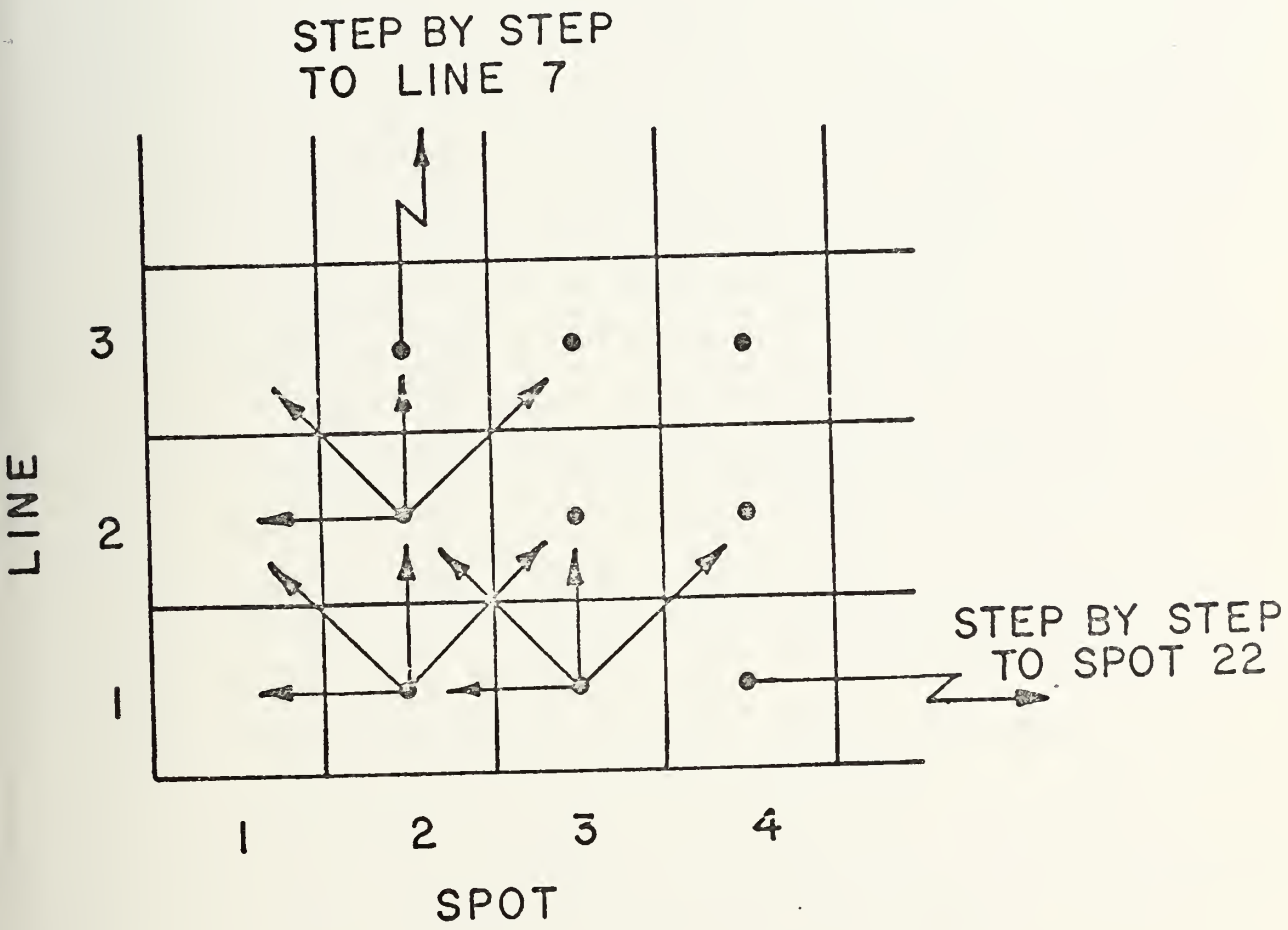


Figure 5. Scanning patterns used by the National Environmental Satellite Service (NESS) for pair comparison in determining VTPR clear-column radiance.

Research on refining the accuracy of determination of clear-column radiances is actively being conducted. This involves both instrumental accuracy improvements as well as the algorithms for the extrapolations of cloud amounts to zero.

III. TRANSMITTANCE MODELS IN THE VTPR CHANNELS

A. ATMOSPHERIC TRANSMITTANCE COMPUTATIONS: GENERAL CONSIDERATIONS

Atmospheric transmittances for the six carbon dioxide spectral intervals used in the retrieval are fundamental and must be computed accurately. The resultant transmittance in any given channel and at any pressure level P(J) in the atmosphere may be expressed as the product of the transmittances due to the carbon dioxide alone $\tau[C(J)]$ and the overlapping transmittances due to the integrated ozone, OZ(J), and water vapor, U(J), from the top of the atmosphere to the level J respectively. Thus

$$\tau(J) = \tau[C(J)]*\tau[U(J)]*\tau[OZ(J)] \qquad (3)$$

Here C(J) denotes the total absorber mass of the carbon dioxide from P(1) = 0.01 mb to P(J). The symbol OZ(J) denotes the corresponding absorber mass of ozone expressed in NTP standard amounts per square centimeter column above level J, and U(J) is the precipitable water vapor in the same column. As an example of the transmittances produced by the program discussed in this thesis, sample outputs are included following the program listing.

Moran (1974) used only carbon dioxide transmittances acting in the vertical column (i.e., $\tau[U(J)]=\tau[OZ(J)]=1$, by assumption) and further simplified the computation by selecting

a mid-latitude, standard-atmosphere transmittance model for carbon dioxide in the six listed channels. Moran found that super-adiabatic temperature lapse rates tended to occur between the 1000 mb and 900 mb levels. Consequently he found it necessary to adjust the values of the transmittance profile somewhat arbitrarily in channels 5 and 6, since the transmittance from the surface in these channels tended to be somewhat higher than with the more realistic product transmittances of Eq. 3.

Transmittances in the carbon dioxide channels were based upon the laboratory observations of the carbon dioxide infrared spectrum and resultant calculations by Drayson (1966), made on a line-by-line basis assuming a homogeneous path (for a fixed temperature).

In calculations applied to non-homogeneous vertical paths, Smith (1969), calculates the carbon dioxide transmittances corresponding to the U. S. Standard Atmosphere (1962); and makes improvements on the usual Curtis-Godson modifications [Goody (1964)] applied to path transmittances for varying pressure, temperature, and absorber masses. In addition, modified profiles corresponding to temperature differences from the U.S. Standard Atmosphere by ±10, ±20, and ±30°K were also computed by Smith, after Drayson's (1966) laboratory calculations. A method for applying temperature corrections to the absorber mass in each non-homogeneous sub-layer was devised so that the effective temperature-modified carbon dioxide transmittances could be adjusted by a variation of

the Curtis-Godson method applied to successive layers, using the laboratory data of Drayson.

The method utilized here for carbon dioxide temperature adjustment along the path will be discussed in greater detail following that for water vapor. This latter method is somewhat more general due to the variable mixing ratio of this constituent in the vertical as well as the greater complexity of the individual line structure in the water vapor infrared spectrum.

B. WATER VAPOR - MIXING RATIO ESTIMATION PROCEDURE

In order to determine the transmissivity due to water vapor in each of the VTPR channels, the precipitable water vapor integrated from J = 01 to any arbitrary level must be determined. For this purpose an estimation procedure for determining the mixing ratio , W(J), at each level was used to represent the water vapor profile. The parameter W(J) was used because it was found to be determined from T(P) alone with reasonable skill, using the method of Weinreb and Crosby (1973); and also because it enters directly into the calculation of the water vapor transmittances in the eight VTPR channels.

The calculation of the mixing ratio W(J) may be derived from

$$W(J) = SAT(T,J)*H(J) \qquad (4)$$

H(J) is the relative humidity and is an unknown function of pressure. The use of the water vapor channel (ν = 535 cm^{-1}) was not attempted for retrieval in this thesis. Furthermore, SAT(T,J), the saturated mixing ratio is a function of temperature T(J) and pressure P(J) only, and is calculated by the GOFF-GRATCH formula [List 1963]

$$\log e_w = -7.90298(T_s/T - 1) + 5.02808 \log(T_s/T) \qquad (5)$$
$$- 1.3816\times10^{-7}[10^{11.344(1 - T/T_s)} - 1]$$
$$+ 8.1328\times10^{-3}[10^{-3.49149(T_s/T - 1)} - 1] + \log e_{ws}$$

Here e_w is the saturation vapor pressure over a plane water surface,

T is the temperature in °K,

T_s is the steam point temperature 373.16 °K, and

e_{ws} is the saturation vapor pressure of water at the steam point temperature.

The value of SAT(T,J) is then computed using the relationship

$$SAT(T,J) = 0.622\left(\frac{e_w}{P(J) - e_w}\right) \qquad (6)$$

Since no equation directly relates the relative humidity to the temperature profile, the mixing ratio was estimated from the saturated mixing ratios at a specified set of eleven levels (Table 2) by a least-squares formulation based solely upon these eleven saturated mixing ratio predictors after Weinreb and Crosby (1973). The method formulates the mixing

ratio W(J) at the 40 levels J = 61,62,...,100 and is given in the form

$$W(J) = \bar{W}(J) + \sum_{I=1}^{11} CREG(I,J)[SAT(I) - \bar{T}(I)] \qquad (7)$$

where $\bar{W}(J)$ is the sample mean mixing ratio at level J over 1100 sample soundings that were used to determine the regression coefficients,

CREG(I,J) is a set of predetermined regression coefficients calculated for each J-level from the 1100 sample soundings,

SAT(I) is the saturation mixing ratio at the level I, where I = 1,2,...,11 is a subset of the 40 J-levels that is found to give the best results (see Table 2), and

$\bar{T}(I)$ is the mean saturation mixing ratio at level I from the 1100 test soundings.

Table 2. Eleven levels used for predictor levels in water vapor retrieval

I	J	P(J) mb
1.	63	209.94
2.	66	245.37
3.	70	299.01
4.	77	412.26
5.	82	509.93
6.	90	699.03
7.	92	753.17
8.	94	810.25
9.	96	870.35
10.	98	933.57
11.	100	1000.00

Thus the method uses an eleven level saturated mixing ratio profile, SAT(I), and converts it into a 40-level mixing ratio profile, W(J), J = 61,62,...,100. The total 100-level

profile is then converted from the 40-level by using the cubic power-law profile due to Smith (1966)

$$W(J) = W(61) \left[\frac{P(J)}{P(61)}\right]^3 \qquad J<61 \tag{8}$$

The mixing ratio is then used in determining the water vapor transmissivity.

C. ADJUSTMENT OF WATER VAPOR MASS IN A NON-HOMOGENEOUS ATMOSPHERE

Assuming that the transmittance by water vapor, $\tau[U(J)]$, in a spectral interval of the VTPR is a known function of the quantity of the precipitable water vapor U, temperature T, and pressure P, an accurate approximation to $\tau[U(J)]$ in the form of a least squares fit polynomial can be calculated. Weinreb and Neuendorfer (1973) proposed such a best-fit model which in effect becomes an analytic function for calculating homogeneous path transmittances. In the Weinreb-Neuendorfer method, an inhomogeneous atmosphere is treated as a sequence of homogeneous layers, each having a constant temperature, pressure, and absorber mass. The transmittance model provides for a homogeneous path as a known function of T, P, and $\tilde{U}$, where $\tilde{U}$ is the effective water vapor mass. If $\tau(J)$ is the transmittance in the spectral interval of the instrument at level J, then

$$\tau(J) = \tau[P(J),T(J),\tilde{U}(J)] \ . \tag{9}$$

The procedure involved in defining $\tau[(J)]$ at each level as depicted in Fig. 6, uses the functional expression, Eq. 15, for layer 1 without modifying the precipitable water vapor mass, U, from its initially specified value based upon the homogeneous values P(1), T(1), and U(1). This gives rise to the following relationship for layer 1

$$\tau(1) = [P(1),T(1),\tilde{U}(1)] \quad . \tag{10}$$

$$\tilde{U}(1) \equiv U(1)$$

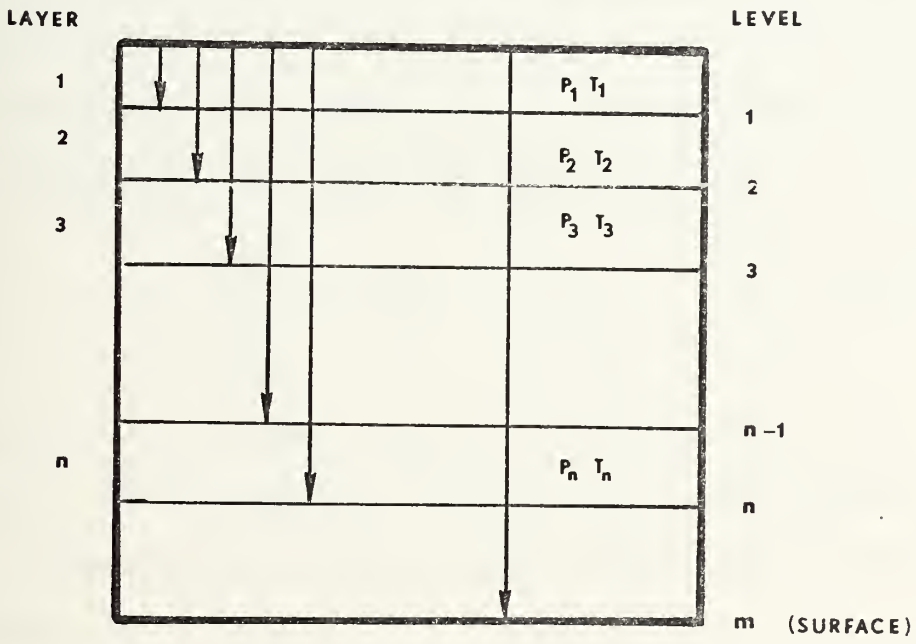


Figure 6. Multi-level atmosphere showing P(J), T(J), and U(J) structures.

In proceeding to level 2, the transmittance through the second layer is affected by the new homogeneous characteristics P(2), T(2), and its water vapor increment ΔU_2, and is no longer along the $\tau[P(1),T(1),\tilde{U}(1)]$ transmittance curve defined by the

conditions in layer 1 (points A_1-B_1 in Fig. 7). It is necessary to determine the adjusted value of water vapor mass, denoted V in Fig. 7, with which the radiant transmittance enters the new homogeneous layer 2. This is accomplished by backing up on curve 2 to $\tilde{U} = V$ by solving

$$\tau(1) = \tau[P(2),T(2),V] \tag{11}$$

for V. The solution for V is accomplished by the Newton-Raphson iteration.

This corrected starting water vapor mass, V, with which to enter layer 2, has been deduced using curve 2 in Fig. 7. For the purpose of computing the transmittance at level 2, the new total water vapor mass is then taken as

$$W = V + \Delta U_2 \tag{12}$$

where ΔU_2 is the known increase in precipitable water vapor in layer 2. This moves the transmittance value $\tau[P(2),T(2),W]$ down to point B_2 on curve 2 where the value of $\tau(2)$ is then taken as

$$\tau(2) = \tau[P(2),T(2),\tilde{U}(2) = W] \tag{13}$$

In proceeding downward to level 3 through the next homogeneous layer of characteristics P(3), T(3), ΔU_3, the corrected amount of water vapor at level 2 is revised from $\tilde{U}(2)$ to V which

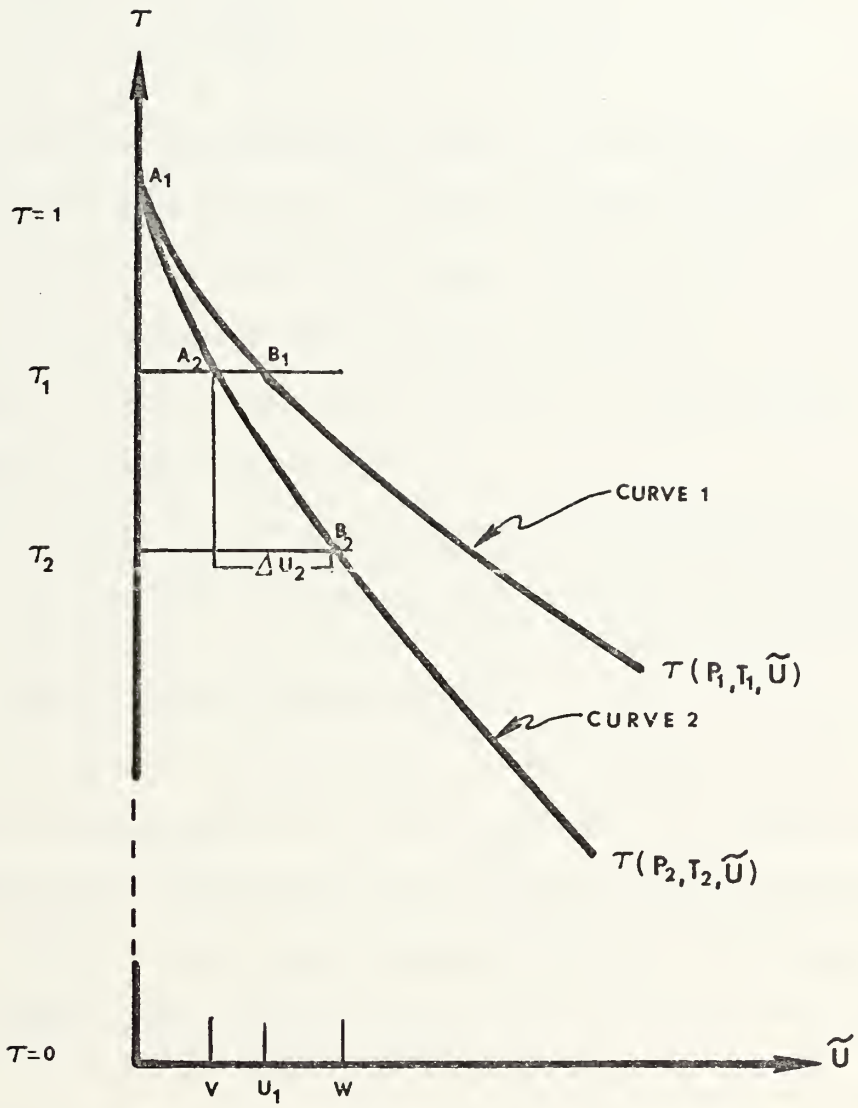


Figure 7. Transmittance curves for atmospheric layers 1 and 2 illustrating modification to effective U(J) in a non-homogeneous atmosphere.

becomes the level 2 starting point of water vapor mass. Hence the new function

$$\tau(3) = \tau[P(3),T(3),\tilde{U}(3)]$$
$$\tilde{U}(3) = V + \Delta U_3 \qquad (14)$$

is solved for the new starting mass at the top of level 3. The procedure continues as a series of Newton-Raphson iterations to correct the effective water vapor masses for the radiant transmittance upon succeeding layers. This procedure is followed through each level J = 2,3,...,99 bounding the top of the 98 layers below J = 2.

The procedure is shown by Weinreb and Neuendorfer to be exact for a Beer's-Law monochronatic transmittance function.

D. WATER VAPOR TRANSMITTANCE MODEL

The water vapor transmittance calculations use the method of Weinreb and Neuendorfer (1973) applied to a modification of the polynomial representation of water-vapor transmission of Smith (1969). The basic equation for the line transmittance of water vapor implies that

$$\ln\{-\ln \tau [U(J)]\} = \sum_{I=1}^{14} C_I X_I \qquad (15)$$

Here

$$X_1 = 1 \qquad X_8 = X_4X_7$$

$$X_2 = (0.1)\ln\frac{UT}{273} \qquad X_9 = X_3X_4$$

$$X_3 = \ln(P/1000) \qquad X_{10} = X_2X_7$$

$$X_4 = \ln(T/273) \qquad X_{11} = X_4X_7$$

$$X_5 = X_2X_3 \qquad X_{12} = (X_4)^2$$

$$X_6 = X_2X_4 \qquad X_{13} = X_3X_6$$

$$X_7 = (X_2)^2 \qquad X_{14} = X_3X_7$$

and C_I is a set of coefficients that were predetermined by fitting Eq. 15 by the least-squares method using line-by-line calculations of the transmittances for 130 homogeneous (constant pressure and temperature) paths. From Eq. 15 it follows that

$$\tau[U(J)] = \exp[-\exp(\sum_{I=1}^{14} C_I X_I)] \tag{16}$$

The values of X_3 through X_{14} are directly calculated only if U is known. However, X_2 must be calculated indirectly since U, the water vapor absorber mass, is essentially a sum of scaled values of ΔU between successive J-levels. Newton's method was used to solve for the new value of X_2, and subsequently other $X_i = X_iX_2$, using the first iteration of

$U_1^{(2)} + \Delta U = U_2^{(1)}$ as the first guess to arrive at the effective $U_2^{(2)}$ at level 2, etc. on to the subsequent J-levels.

Water vapor transmittances in the infrared region have been found to contain a spectral feature not previously explainable by the classical line-spectral approaches. Bignell (1970) found a continuum absorption from the edge of the 20 μm rotational band which overlaps the lines in the water-vapor and carbon-dioxide absorption regions. The continuum absorption coefficient was found to be due to the presence of the water vapor dimer $(H_2O)_2$. The dimer absorption coefficient in the various spectral regions was found to be proportional to $[T(J)]^{-5}$ (see Eqs. 17 below). Thus, it is necessary to add the dimer correction to Eq. 15 to fully account for the combined transmittances of water vapor in all channels. The dimer contribution at level J to the $\ln[-\ln\tau(J)]$ of Eq. 15 due to water vapor is given by the adjusted dimer mass profile in terms of

$$\text{DIMER}(J) = \text{DIMER}(J-1) + \left[\frac{A(J-1)+A(J)}{2}\right][P(J)-P(J-1)]$$

$$A(J) = P(J)[W(J)]^2 \left[\frac{303.16}{T(J)}\right]^5 \qquad (17)$$

The actual transmittance due to the effective dimer mass in each channel is then given by

$$\ln[-\ln\,\tau(\text{DIMER})] = B(I)*\text{DIMER}(J) \qquad (18)$$

where B(I), I = 1,2,...,8 is a set of 8 constant absorption coefficients, the values of which have been given for each channel after Bignell (1970). The combined water-vapor transmittance in each channel then becomes

$$\tau[U(J)] = \exp\{-\exp[DIMER(J)*B(I)]\}\ \tau(J) \qquad (19)$$

where $\tau(J)$ is the value computed using Eq. 16.

The zenith angle correction for water vapor transmittance is included in DIMER(J) and U(J) of Eqs. 9 and 17 by making the following path-corrections for mass:

$$\begin{aligned} DIMER(J) &= DIMER(J)*PATH, \\ U(J) &= U(J)*PATH, \\ PATH &= \sec Z. \end{aligned} \qquad (20)$$

Here sec Z is the secant of the zenith angle from the point representing the center of the box to the radiometer (see Figure 4).

E. CARBON DIOXIDE TRANSMITTANCE MODEL

A polynomial expression for the carbon dioxide transmittance $\tau[C(J)]$ in terms of logarithmic functions similar to Eq. 15 has been shown to be feasible by Smith (1969). However, the absorber mass of carbon dioxide is proportional to pressure, and little dependence upon higher powers of the

ln(P/1000) term has been found necessary to fit line-by-line computations of transmissivities with increasing pressure in non-homogeneous atmospheres.

However, the carbon dioxide polynomial expansion, similar to Eq. 15 for the water vapor model, has been found to be subject to path correction primarily for the temperature variation along the vertical. The method of Weinreb and Neuendorfer (1973) was shown by Fleming (1974) to be converted into the following form

$$\tau[C(J)] = \tau[C(J-1)][\alpha(J)+\beta(J)\Delta T(J)+\gamma(J)\Delta T^2(J)] + \theta_i\{\tau[C(J-1)]-\tau^*(J-1)\} \quad (21)$$

where $\tau[C(J)]$ is the transmittance due to carbon dioxide at level J:

$\Delta T(J)$ is the temperature difference between the U. S. Standard Atmosphere (1962) and the average temperature over the layer bounded by the pressure levels J and J-1 (J = 2,3,...,100),

α,β,γ are a set of 3 by 100 transmittance factors that are tuned specifically to the filters of the instrument in use for the data period,

θ_i is a set of six adjustment factors applicable to systematic corrections for temperature variations from the initial standard, and

$\tau^*(J)$ is a correction term approximated after the Newton-Raphson method from

$$\tau^*(J) = \frac{A(J)+B(J)\Delta T(J)}{\Delta T(J-1)} + \frac{D(J)[\Delta T(J)]^2}{[\Delta T(J-1)]^2} \quad (22)$$

where for the initial level J = 1, A, B, D are defined as

$$A(1) = \alpha(1)$$

$$B(1) = \beta(1)\Delta T(1) \tag{23}$$

$$D(1) = \left[\frac{\beta(1)\beta(2)}{\alpha(1)} + \gamma(1)\right][\Delta T(1)]^2$$

and for subsequent layers, J > 1, the values of A, B, and D are updated iteratively by

$$A^{(1)}(J) = A^{(2)}(J-1)$$

$$B^{(1)}(J) = \frac{B^{(2)}(J-1)\Delta T(J)}{\Delta T(J-1)} \tag{24}$$

$$D^{(1)}(J) = \frac{D^{(2)}(J-1)[\Delta T(J)]^2}{[\Delta T(J-1)]^2}$$

$$D^{(2)}(J) = \frac{D^{(1)}(J)[\Delta T(J)]^2\alpha(J)}{[\Delta T(J-1)]^2} + A^{(1)}(J)\gamma(J)[\Delta T(J)]^2$$

$$B^{(2)}(J) = B^{(1)}(J)\alpha(J) + A^{(1)}(J)\beta(J)\Delta T(J)$$

$$A^{(2)}(J) = A^{(1)}(J)\alpha(J)$$

all of which must be computed in the given order.

F. OZONE TRANSMITTANCES

The ozone transmittances $\tau[OZ(J)]$ are minor contributions appearing in the form of Eq. 3 for each carbon dioxide channel.

They are constant in each channel at a given level, varying, however from level to level. Thus the effect of $\tau[OZ(J)]$ is expressible in the form of a 6 by 100 array, one member of the array for each carbon dioxide channel at each J-level. The channel values of $\tau[OZ(J)]$ used here are listed in Appendix B, as extracted from the NESS CLRAD program.

The $\tau[OZ(J)]$ values in Appendix B have not been path corrected and are based upon globally averaged NTP absorber paths of ozone in the carbon dioxide channels.

G. TRANSMISSIVITY ADJUSTMENT FOR ZENITH ANGLE

When the transmittance in the spectral interval of the VTPR has been calculated, an adjustment must be made to account for the path differences that occur with various zenith angles. The VTPR is designed to measure clear-column radiances from points which subtend a zenith angle of 23°47' left, 0°, or 23°47' right of the satellite track. These angles correspond to the center of the three boxes shown in Figure 3. The adjustments to the calculated transmittances must be made for these basic angles and any small deviations from them.

The principle of the correction stems from the fact that if the zenity angle is other than zero degrees, the atmospheric absorbers will have more effect due to the geometry involved (Figure 4) with the longer path, and, therefore, the transmissivity in the layer will be decreased level for level.

The correction for both the carbon dioxide and ozone transmittance at level J is taken from a section of the NESS CLRAD program [McMillin(1974)] and is in the form of

$$\tau(J) = \tau(J)^{A} \tag{25}$$

$$A = (PATH)^{B(J)} \tag{26}$$

where PATH is the secant of the zenith angle, and B(J) is a polynomial function for carbon dioxide alone. For the ozone path corrected transmittances $B(J) \equiv 1$ for all atmospheric levels. B(J) is a function of ln[P(J)] with terms in ln[T(J)] up to quadratic (and a product of these logarithmic functions), with a set of five predetermined constants for each channel. These constants have been tuned for the particular VTPR instrument in use during the period.

IV. RETRIEVAL OF TEMPERATURE PROFILES

A. INPUT DATA USED FOR TEMPERATURE RETRIEVAL

1. First Guess Temperatures

In addition to the climatological soundings, T(P), from the U. S. Standard Atmosphere Supplements (1966) (see Appendix B), the retrieval program requires a first guess temperature profile in the box center for each VTPR clear-column radiance set. The first guess temperatures are of two basic types depending upon the latitude of the sounding. For tropical latitudes, from the equator to 18 degrees North, radiosonde data is averaged over all latitudes and longitudes to provide a single climatological first guess profile. For the other northern hemisphere retrievals, the first guess profile comes from an application of the National Meteorological Center (NMC) prognostic model for a period of 12 to, at most, 18 hours from the preceding complete analysis. The profile is extrapolated in time and space to the VTPR clear-column sounding location.

The first guess temperatures, as read into the program, give temperatures at the 15 mandatory levels shown by an asterisk (*) in Table 3, from 100 mb to 10 mb. The U. S. Standard Atmosphere Supplement climatology value is adjusted for latitude and month and then fitted to the first guess profile at the 10 mb level. The adjustment, defined as first guess (10 mb) minus standard (10 mb), is then added to all values of the standard

Table 3. 56 level atmosphere with merged climatology and 15 level (*) first guess field for sample sounding.

LEVEL	PRESSURE (mb)	TEMPERATURE (°C)
1	0.01	-87.130
.	.	.
.	.	.
.	.	.
23	1.00	-04.311
.	.	.
.	.	.
.	.	.
34	10.00*	-42.300
35	15.00	-45.300
36	20.00*	-49.925
37	25.00	-53.175
38	30.00*	-56.800
39	40.00	-59.900
40	50.00*	-63.000
41	60.00	-65.600
42	70.00*	-68.200
43	85.00	-69.250
44	90.00	-69.600
45	100.00*	-70.300
46	150.00*	-63.400
47	200.00*	-58.200
48	250.00*	-48.400
49	300.00*	-38.900
50	400.00*	-23.600
51	500.00*	-11.800
52	600.00	-03.500
53	700.00*	4.800
54	850.00*	13.600
55	900.00	16.267
56	1000.00*	21.600

atmosphere, above 10 mb, and the profile is expanded to the 56 levels shown in Table 3.

The 56 level temperature profile is then expanded to the 100 J-levels, where the pressure at level J is given by

$$P(J) = 0.01[1+(J-1)(0.26087836)]^{7/2} \qquad (27)$$

where J = 1,2,...,100 and defines the pressure from 0.01 mb to 1000 mb.

2. Other Input Data

The remaining input data required, having given the VTPR first guess sounding, includes the zenith angle, sea surface temperature, and clear-column radiances. This data, along with all of the verifying radiosondes and first guess temperature profiles to 10 mb was kindly provided by NESS in the form of an archival tape.

B. MATHEMATICAL DEVELOPMENT OF THE TEMPERATURE RETRIEVAL

Given a non-scattering atmosphere in thermodynamic equilibrium, the clear-column spectral radiance at the top of the atmosphere in each channel is related to the vertical temperature profile and the absorber mass structure by the RTE, Eq. 1.

The right hand side of Eq. 1 is composed of an earth's surface radiation term, and an atmospheric contribution which is integrated from the surface of the earth (1000 mb) to the top of the atmosphere (0.01 mb).

When the 100 J-levels developed in Eq. 27 are used, Eq. 1 can be rewritten

$$I_i = B_i[T(100)]\tau_i(100) + \int_{J=100}^{J=1} (B_i[T(J)] \frac{d\tau_i(J)}{dJ}) dJ \tag{28}$$

The Planck radiance function used in Eq. 28 at level J and in channel i is

$$B_i[T(J)] = \frac{(C1)*\nu_i^3}{\exp[\frac{C2\nu_i}{T(J)}] - 1} \tag{29}$$

where ν_i is the wave number in channel i,

C1 is the constant 1.9061×10^{-5} erg cm^2 sec^{-1} $ster^{-1}$, and

C2 is the constant 1.43868 cm °K.

In order to reduce the effect of truncation error in the integration function of the RTE, and increase overall stability, the 100-level atmosphere was reduced to a 33-layer atmosphere as shown in Fig. 8. In integrating the RTE over the 100 level atmosphere, Simpson's rule was applied over each sublayer K centered at the fractional J levels of the K-layered atmosphere (Fig. 8). The main virtue of the Simpson quadrature scheme using the weighting factors of 1, 4, 1 over each layer (e.g., J = 01, 02.5, 04), lies in the small discretization error, $(1.5)^5/90$ times the fourth derivative with respect to J of the integrand function of Eq. 28, in substitution of the finite summation for the Riemann integration. The determination of T

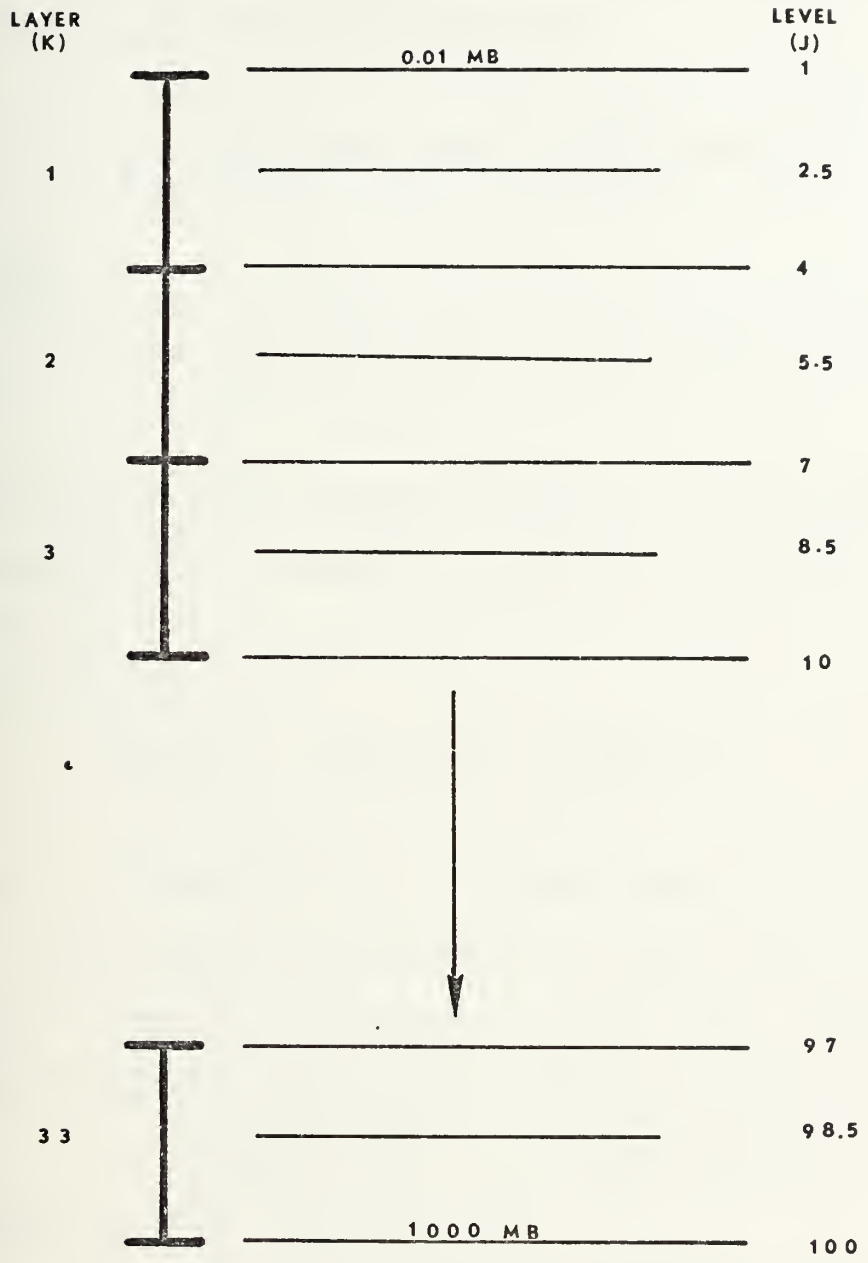


Figure 8. Thirty three K-layer atmosphere model used for the integration of the Radiative Transfer Equation.

at levels J = 02.5 etc., is accomplished by interpolation of the T(P) using the $P^{2/7}$ pressure levels, defined by Eq. 27. Therefore, Eq. 28 can be rewritten

$$I_i = B_i[T(100)]\tau_i(100) + \sum_{K=1}^{33} \bar{B}_i(K)\Delta\tau_i(K) \quad , \tag{30}$$

where

$$\bar{B}_i(K) = \frac{1}{6}\{B_i[T(J_K-1.5) + 4B_i[T(K)] + B_i[T(J_K+1.5)]\} \tag{31}$$

is the layer-mean Planck function for layer K employing Simpson's rule. Moreover $\Delta\tau_i(K)$ now spans three J levels (Fig. 8),

$$\Delta\tau_i(K) = \tau_i(J_K-1.5) - \tau_i(J_K+1.5) \tag{32}$$

where J_K is the value of J at the center of layer K.

Using the inversion method of Smith (1970) as modified by Martin (1974), the retrieval of mean layer temperatures is determined from clear-column radiance values as follows:

1. Determine the first guess radiance value in channel i, $I_i^{(1)}$, using Eq. 30.

2. Form the residual by comparing the clear-column radiance with the computed value from Eq. 30, using

$$R_i^{(1)} = I_{i\text{-CLEAR}} - I_i^{(1)} \tag{33}$$

3. If the residual is not close to zero the first guess temperature profile $T^{(1)}(P_{J_K})$ must be improved to $T^{(2)}(P_{J_K})$ in accordance with

$$B_i[T^{(2)}(P_{J_K})] = B_i[T^{(1)}(P_{J_K})] + R_i^{(1)} \tag{34}$$

This tends to move the temperature profile closer to the final desired convergent profile. If n steps are required to converge the residual close to zero, the final step is

$$B_i[T^{(n+1)}(P_{J_K})] = B_i[T^{(n)}(P_{J_K})] + R_i^{(n)} \tag{35}$$

where finally

$$\frac{R_i^{(n)}}{\overline{I}_{i\text{-CLEAR}}} \leq 10^{-4} \tag{36}$$

When a convergent Planck function is determined for each channel, i, and at each level, J, the temperature at that level can be determined by solving Eq. 29 for T(J). The value of the Planck function in this case must be a weighted-mean Planck using the six values of $B_i(J)$, i = 1,2,...,6, at each J-level. Figure 9 shows the values of transmittance in each of the six channels with respect to $P^{2/7}$, that is, with respect to the linear J-scale. Figure 10, the first derivative with respect to J of the transmittances in Fig. 9, is the

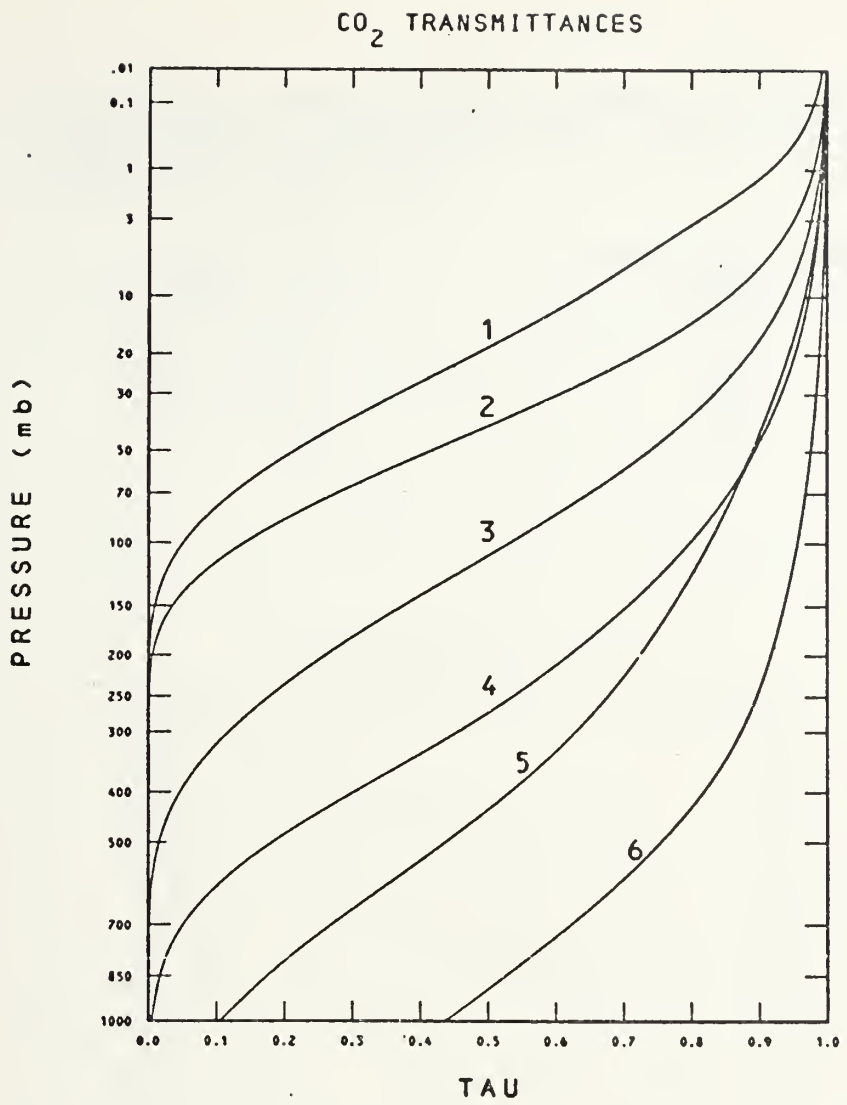


Figure 9. Carbon dioxide transmittances channels 1 through 6, after McMillin et al. (1973.

weighting function used in determining this weighted mean Planck. The usual procedure as used by Smith et al. (1972), involves the use of a constant normalized wave number ($\bar{\nu}$ = 700 cm^{-1}) in Eq. 37, whereas in this thesis, a normalized wave number, decreasing with decreasing values of pressure was found to give a more accurate result, similar to results of Moran (1974). By using this varying wave number (Table 4), advantage can be taken of the level of maximum contribution of

Table 4. Normalized wave numbers and corresponding pressure levels used in inverting the Planck function for temperature retrieval.

Pressure P(J) mb	Wave Number ($\bar{\nu}$) cm^{-1}
1000 - 351	720
350 - 96	710
95 - 0.01	690

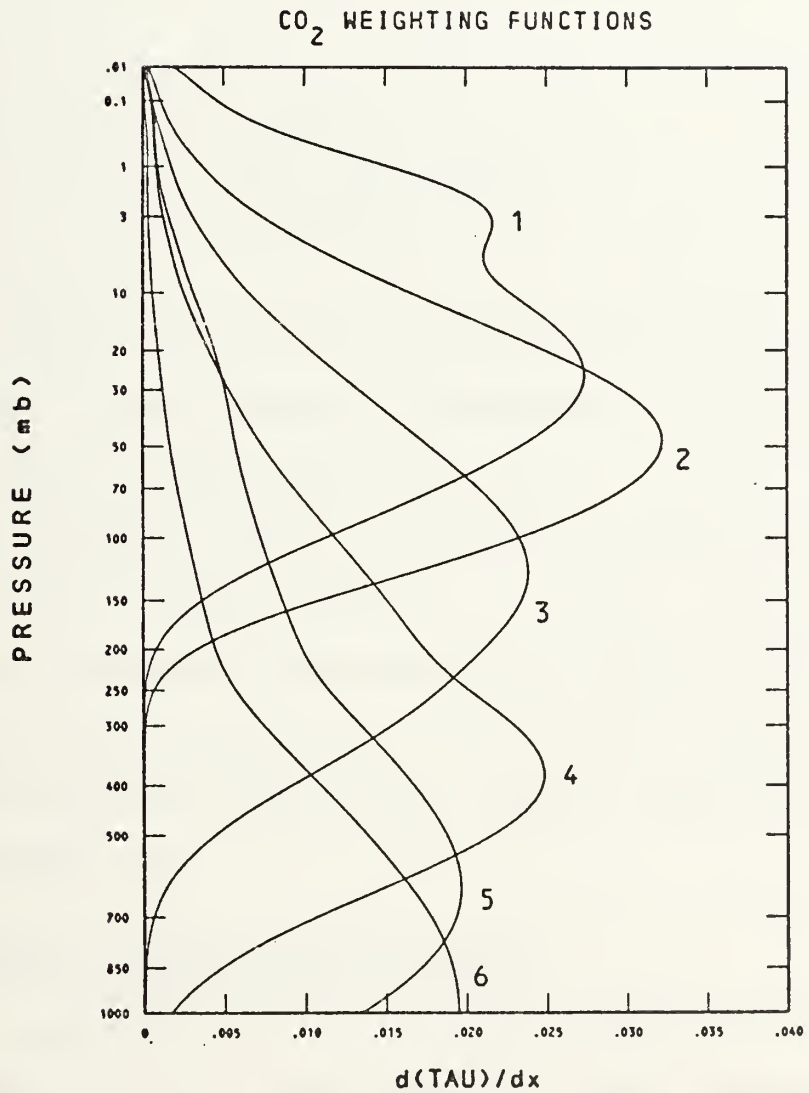


Figure 10. Weighting functions used in determining a weighted mean Planck function.

that channel to the derived equivalent blackbody temperature. The weighted mean Planck function then becomes

$$B^{(n)}[\bar{\nu},T(J)] = \frac{\sum_{i=1}^{6} B_i^{(n)}(J)\ \Delta\tau_i(J)}{\sum_{i=1}^{6} \Delta\tau_i(J)} \quad . \tag{37}$$

By using this weighted Planck, the 100 mean temperatures, $\bar{T}(J)$, can be determined by the inversion of Eq. 29

$$\bar{T}(J) = \frac{C2\ \bar{\nu}}{\ln\left[\frac{C1\bar{\nu}^3 + B^{(n)}(\bar{\nu},J)}{B^{(n)}(\bar{\nu},J)}\right]} \quad . \tag{38}$$

In Eqs. 37 and 38, which are accomplished after the iteration procedure in each channel is complete, the values of $\Delta\tau_i(J)$ are centered differences taken over $\Delta J = 2$, but centered on each individual J level. A forward $\Delta\tau_i$ difference is used to initiate the process at level J = 1 and a backward difference is used to terminate the weighting process at J = 100. In this solution procedure, Eqs. 37, 38, the algorithm used is essentially after Smith et al. (1972), except for the use of the variable $\bar{\nu}$.

C. STEPWISE TEMPERATURE RETRIEVAL

The procedure for retrieving the layer-mean temperatures for layer J = 1,2,...,100, from the clear-column radiances can be summarized as follows (program names refer to the listing at the end of this thesis).

1. Input the necessary data.

    a. sounding latitude.

    b. zenith angle.

    c. 15-level first guess temperatures.

    d. sea surface temperature.

    e. clear-column radiances in channels 1 to 6.

2. Expand the 15-level first guess temperature profile to 56 levels and merge it with climatology at the 10 mb level using subroutine UPPER.

3. Expand the 56-level temperature profile to 100 levels using Eq. 27 and subroutine LEVELL.

4. Calculate the atmospheric transmittance due to carbon dioxide in channels 1 through 6 at each level J using subroutine RDTEMP and adjust for the zenith angle by using subroutine MARTAU.

5. Calculate the water vapor content of the atmosphere in the form of a mixing ratio profile, one value at each level J, using function GOFF and Eqs. 7 and 8.

6. Use the mixing ratios to calculate the path corrected atmospheric transmittance due to water vapor in channels 1 through 6 at each level J using subroutine TRANW. (Note: steps 5 and 6 were performed on the first iteration only, due to the small change in water vapor transmissivity from the first guess to the final temperature profile.

7. Calculate the total atmospheric transmissivity in each channel and at each level through the product of Eq. 3 which uses path corrected values of transmittance due to carbon dioxide, water vapor, and ozone.

8. For the first iteration, using the 100-level first guess temperatures, the Planck functions must be calculated in each of the 6 channels.

a. Calculate the 100 J-level Planck functions using Eq. 29.

b. Calculate the 33 K-level Planck functions by fitting a fourth order Lagrangian polynomial to the 100 J-level Planck-profile [after Conte and deBoor (1965)].

9. Calculate the $\Delta\tau(J)$ for each channel in the 100 J-level and $\Delta\tau(K)$ for the 33 K-level atmospheres. The $\Delta\tau(K)$ will be used in the discretized form (Eq. 30) of the RTE, in order to reduce the truncation error associated with the finite summation, substituted for the Riemann integration of the integrand function in Eq. 28. This is important while dealing with the $\tau(J)$ values which occur before the temperature profile and its associated transmissivities have converged. The converged $\Delta\tau(J)$ will be used with Eq. 37 in producing the new 100-level temperature profile.

10. Compute the layer-mean Planck values by Eq. 31.

11. Compute the radiance in each channel using Eq. 30 and determine the residual difference between the clear-column radiance and the computed radiance, Eq. 33.

12. If the residual value is not close to zero, another iteration must be performed to improve the accuracy of the retrieved temperature profile.

a. Calculate the new 100-level and 33-level Planck functions by adding the residual to each previous value, Eq. 34.

b. Calculate the new 100-level temperature profile using Eqs. 37 and 38, and go back to step 4. Continue recycling until convergence is achieved (see Eq. 36).

13. If the residual is small enough (Eq. 36 is true), go directly to the calculation of the new 100-level temperature profile, Eqs. 37 and 38.

D. PROGRAM OUTPUT

The program is designed to produce a mean layer temperature profile at 100 levels from 1000 mb to 0.01 mb. For the purpose of testing the accuracy of these retrieved temperatures, additional inputs were needed.

First a set of radiosonde soundings, as close as possible to each retrieval site in latitude, longitude, and real time was read in. While these soundings are not considered to be the exact state of the atmosphere at the retrieval site, they are as close as possible and therefore were used to determine the error in the retrieval program at each level J by using

$$\text{ERROR}(J) = T(J) - AT(J) \tag{39}$$

where T(J) is the retrieved temperature, and

AT(J) is the radiosonde sounding temperature.

Secondly, a set of retrieved temperatures supplied from NESS for each case investigated was read in and compared with the radiosonde temperatures.

The program then output the following for each of the 233 retrievals attempted (see sample output following the program listing):

1. Station number (1,2,...,233)
2. Sounding zenith angle in degrees.
3. Station latitude.
4. The adjustment at 10 mb necessary to fit the first guess temperature profile to the climatological temperatures.
5. The number of iterations necessary for convergence.
6. Table of results, listing for each of the 15 levels:
   a. Pressure
   b. Retrieved temperature
   c. Radiosonde sounding temperature
   d. Error (retrieved - sounding)
   e. NESS retrieved temperature
   f. Error (NESS retrieved - sounding)

In order to easily compare the accuracy of the retrieval with the radiosonde data and also to compare the error of this method with that of NESS, histograms were drawn and statistical data were obtained. The errors were compared level for level on an overall basis (globally averaged) and also on a latitude-band basis for the latitude ranges shown in Table 5.

Table 5. Latitude bands used for error analysis of the VTPR retrieved temperatures.

LATITUDE BAND	BAND WIDTH
1	$0 \leq LAT < 20N$
2	$20N \leq LAT < 40N$
3	$40N \leq LAT < 60N$
4	$60N \leq LAT$

V. RESULTS OF THE VTPR TEMPERATURE RETRIEVAL

In general, the errors (retrieved temperature - radiosonde temperature) were less than 5 °K when averaged over the latitude-bands shown in Table 5. The errors also compared favorably with the results of the NESS VTPR retrieval in all 15 atmospheric levels and the four latitude bands. In calculating the errors, the assumption that the radiosondes matched the VTPR retrieval sites exactly in time and space was made. The difference, though small (averaging ±0.6 degrees in latitude, ±0.7 degrees in longitude, and ±1.87 hours in time), coupled with the small data base of 233 retrievals, could have had some effect on the results and should be of some consideration.

A. GLOBAL RESULTS

The global mean results obtained here are summarized in Table 6 along with the averaged results from the NESS retrievals. The frequency distributions of the global error analysis at each of 15 key atmospheric levels are shown as a function of the error classes encountered (See Appendix A-1 to A-15). These frequency distributions, in the form of histograms, are included as a visual aid in analyzing the deviation of the error from the mean. They show that even though the range of errors can extend over as much as 20 °K, the probability of a relatively large error is much less than the probability of the small errors in the vicinity of the mean.

Table 6. Retrieved temperature error analysis on a global basis.

PRESSURE (mb)	RETRIEVAL		NESS		NO. OF SAMPLES
	MEAN ERROR (°K)	RMS ERROR	MEAN ERROR (°K)	RMS ERROR	
10	-0.55	4.00	-0.75	4.51	59
20	0.57	3.25	-0.11	2.72	112
30	-0.06	3.20	-0.17	3.12	142
50	0.37	3.20	-0.17	3.12	142
70	0.75	4.39	0.91	5.12	179
100	-0.45	3.89	-2.30	5.12	179
150	-0.30	2.58	-1.51	2.73	208
200	-0.66	3.33	-1.04	3.29	215
250	0.15	3.22	0.41	3.33	206
300	-0.58	2.82	0.24	2.70	223
400	-0.18	2.79	-0.09	2.07	226
500	-0.67	3.09	-0.32	2.13	227
700	-0.99	3.29	-0.86	2.81	226
850	-0.08	3.26	-0.31	3.55	227
1000	-0.24	1.77	0.26	3.89	196

B. LATITUDE BAND RESULTS

Because of space limitations, frequency distributions were not included for the latitude band results. However, Table 7 furnishes a summary of the latitude band analysis of errors including their root mean square errors along with the corresponding NESS results.

Table 7. Retrieved temperature error analysis on a latitude band basis (including the corresponding NESS results in parentheses). For each level in each latitude band the listings are: mean error in °K
root mean square error
sample size

PRESSURE (mb)	LATITUDE BANDS IN DEGREES NORTH 0 - 19.9	20 - 39.9	40 - 59.9	>60
10	-2.10(-3.54) 4.00(5.16) 13	-0.62(1.54) 4.87(5.54) 18	0.58(0.91) 3.78(3.66) 21	-0.91(2.47 2.05(4.37) 7
20	-1.22(-2.43) 2.73(3.32) 18	1.54(0.11) 3.26(2.50) 36	1.29(1.02) 3.37(2.48) 44	-1.88(-1.25) 3.60(3.47) 14
30	0.95(0.15) 2.73(3.32) 22	1.28(1.77) 3.26(2.50) 45	-0.34(-5.46) 3.37(6.48) 56	-1.88(-1.25) 4.61(4.94) 19
50	4.48(4.50) 5.59(5.81) 23	1.56(2.99) 3.46(4.18) 60	-0.75(-0.89) 2.85(2.96) 73	-3.53(-4.03) 4.23(6.10) 23
70	1.00(8.48) 3.49(9.09) 23	1.64(3.14) 3.49(4.34) 60	-0.89(-1.30) 3.02(3.40) 73	-3.55(-5.43) 4.25(5.99) 23

Table 7 (Continued)

PRESSURE (mb)	LATITUDE BANDS IN DEGREES NORTH 0 - 19.9	20 - 39.9	40 - 59.9	>60
100	2.93(1.08) 4.87(3.32) 27	-0.66(0.54) 2.96(3.13) 64	-1.80(-4.03) 3.52(5.02) 86	-4.62(-7.41) 5.38(7.86) 24
150	1.09(-0.30) 3.01(1.84) 29	0.73(-1.24) 2.75(2.92) 66	-1.21(-2.13) 2.27(2.92) 89	-1.38(-1.47) 2.64(2.42) 24
200	-0.09(-1.12) 2.12(2.09) 31	-0.81(-2.46) 3.77(3.39) 69	-0.82(-0.47) 3.49(3.38) 91	-0.33(1.00) 2.69(2.43) 24
250	-0.12(-0.51) 2.10(1.73) 29	-0.42(-1.18) 3.19(3.15) 66	0.46(1.37) 3.47(3.59) 88	0.96(2.43) 3.69(4.36) 23
300	0.07(-1.11) 2.43(2.13) 32	0.35(-0.83) 2.68(2.82) 71	-0.24(1.21) 2.83(2.71) 94	0.15(1.32) 2.98(3.08) 26

Table 7 (Continued)

PRESSURE (mb)	LATITUDE BANDS IN DEGREES NORTH 0 - 19.9	20 - 39.9	40 - 59.9	>60
400	-0.44(-0.50) 1.53(1.33) 33	-0.09(-0.12) 2.58(2.14) 73	-0.43(0.04) 3.19(2.32) 94	0.77(-0.01) 3.15(1.70) 26
500	-0.07(0.80) 1.71(1.56) 33	-0.79(-0.30) 2.68(2.17) 73	-1.06(-0.54) 3.44(2.22) 95	0.34(-0.92) 4.15(2.98) 26
700	-0.91(0.64) 1.95(1.92) 34	-1.19(-0.42) 2.64(2.53) 70	-1.33(-1.47) 3.87(3.36) 97	0.70(-1.88) 4.09(3.04) 26
850	0.57(2.27) 2.44(3.10) 34	0.20(0.94) 2.64(2.94) 70	-0.45(-1.18) 3.86(3.35) 97	-0.30(-3.81) 4.19(5.69) 26
1000	0.57(1.71) 1.11(2.91) 33	-0.36(1.08) 2.19(3.25) 64	-0.55(-0.69) 1.65(3.74) 80	0.11(-3.68) 1.76(7.26) 19

VI. CONCLUSIONS

The first objective of this thesis was to incorporate the state-of-the-art methods [as used by Fritz et al. (1972)] in calculating atmospheric transmittances, into the retrieval scheme. The method involved here for calculating the effects of water vapor, ozone, and carbon dioxide transmittance proved to be satisfactory. This, coupled with the inclusion of a 33 level integration scheme and the use of a variable wave number, as opposed to the constant $\bar{\nu}$ = 700 cm^{-1}, combined to give results comparable to those of NESS.

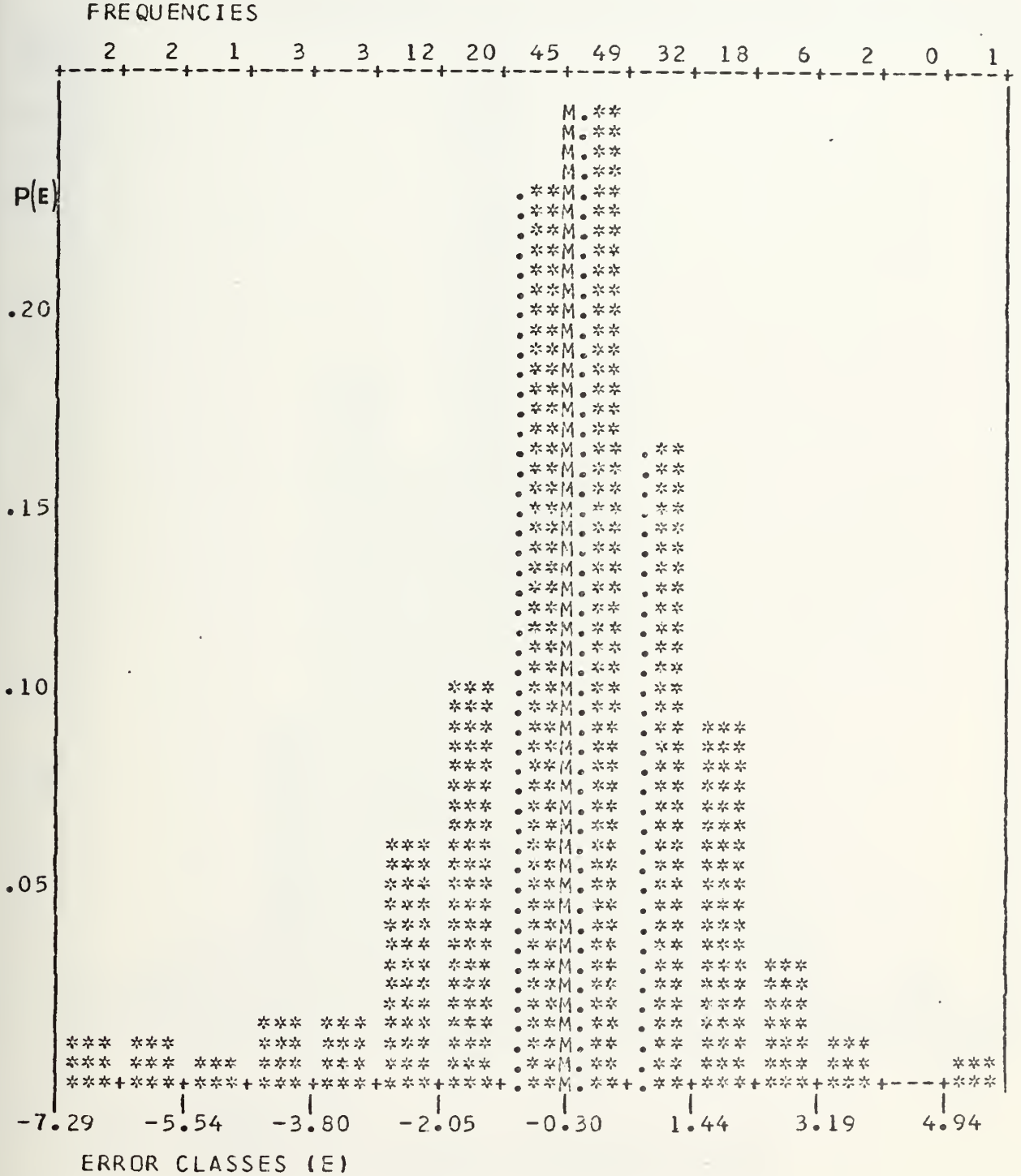
The temperature profile convergence occurred after an average of 5 iterations. While this is an improvement over the Moran (1974) model, as would be expected with the more sophisticated procedures incorporated, the number of iterations required would possibly be reduced further through the use of a more accurate first guess temperature profile. Gelman et al. (1972) used a regression technique for estimating the first guess temperatures above 10 mb, as opposed to merging with the standard atmosphere climatology as used here. Since this regression technique of Gelman produces a more accurate first guess temperature profile, it would reduce the number of iterations required for convergence even further. However this program was not available locally for inclusion in this thesis.

The second objective, that of evaluation through comparison with matching radiosondes, showed that the retrieval system produced errors that were comparable to NESS retrievals, or better, especially in the area of the tropopause. The small data base of 233 soundings is not considered large enough to evaluate the accuracy of the retrieval system beyond that, and more experimentation with a larger sample, and inclusion of the Gelman regression technique is required.

It is concluded that this thesis has demonstrated a consistent and accurate means of temperature profile retrieval from VTPR clear-column radiance data.

APPENDIX A-1

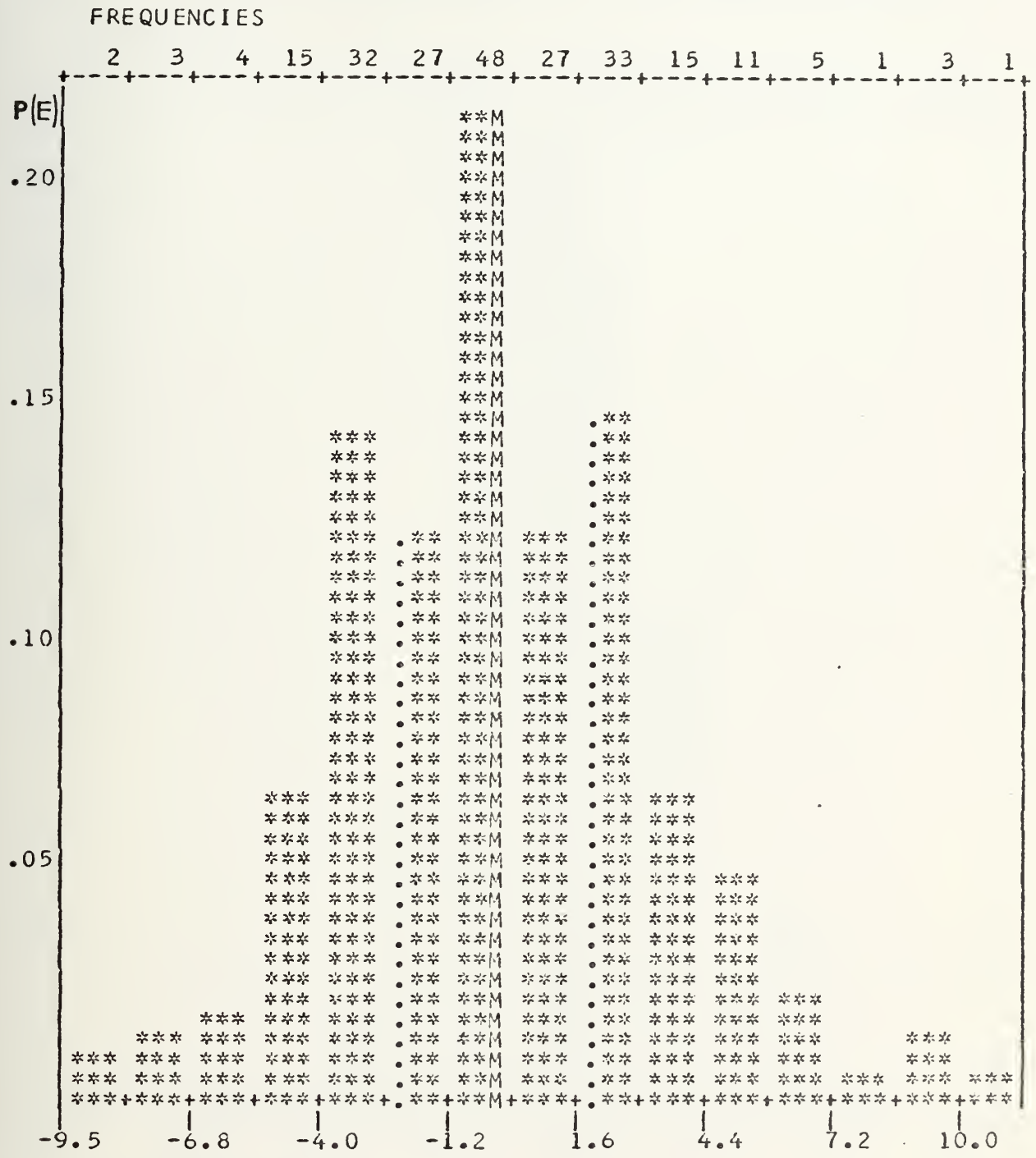
Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 196.



1000 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX A-2

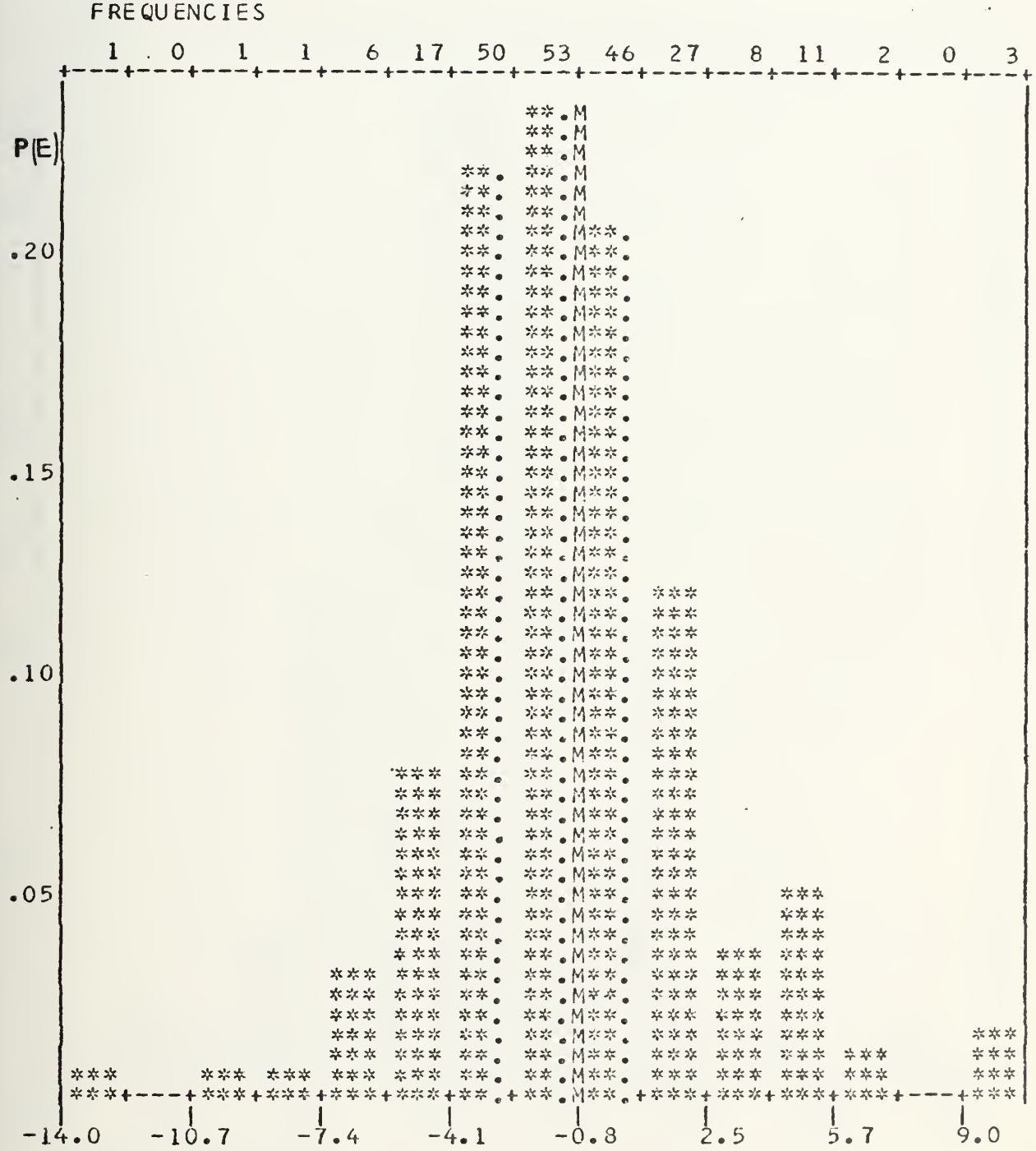
Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 227.



850 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX A-3

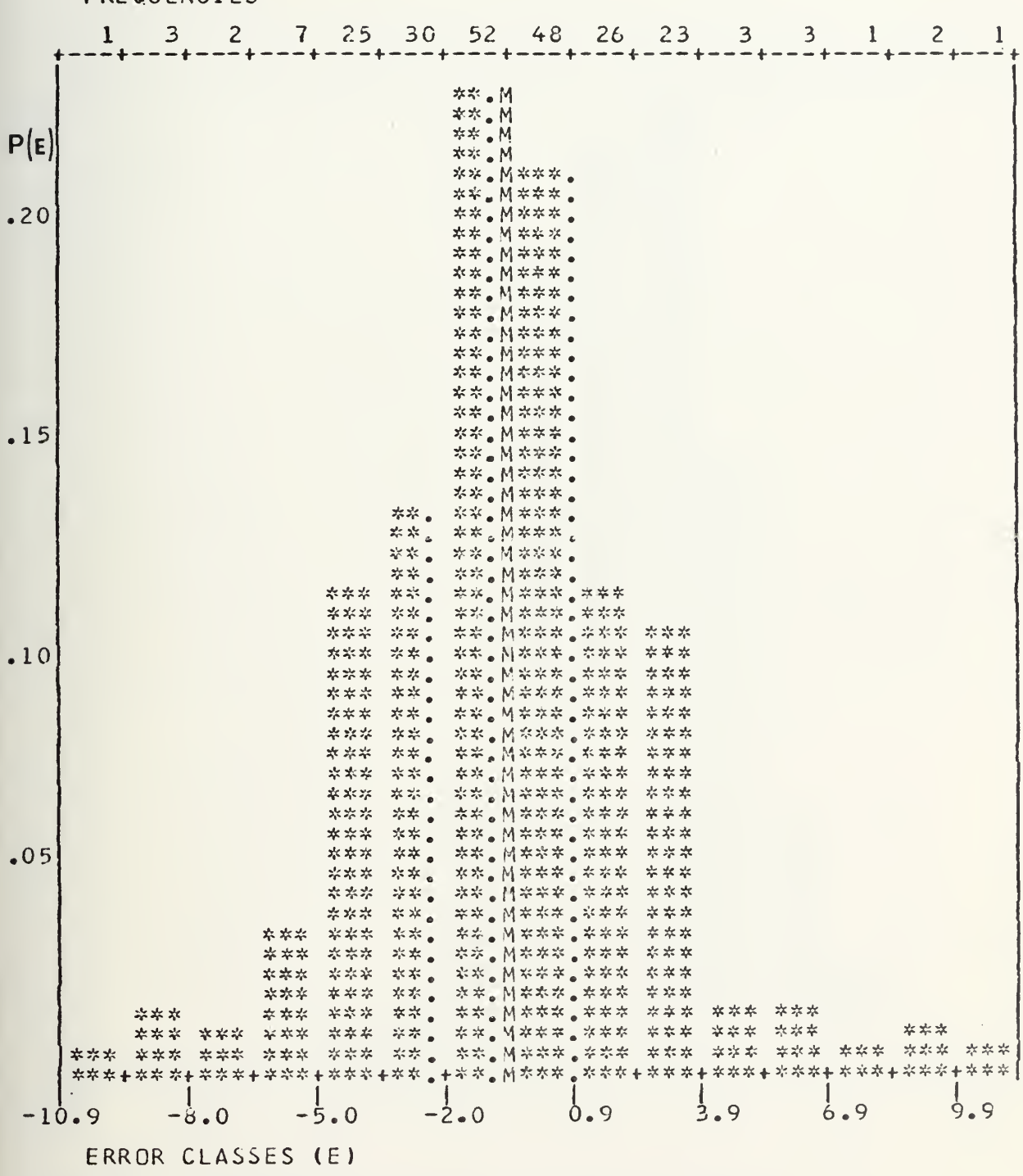
Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 226.



700 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX A-4

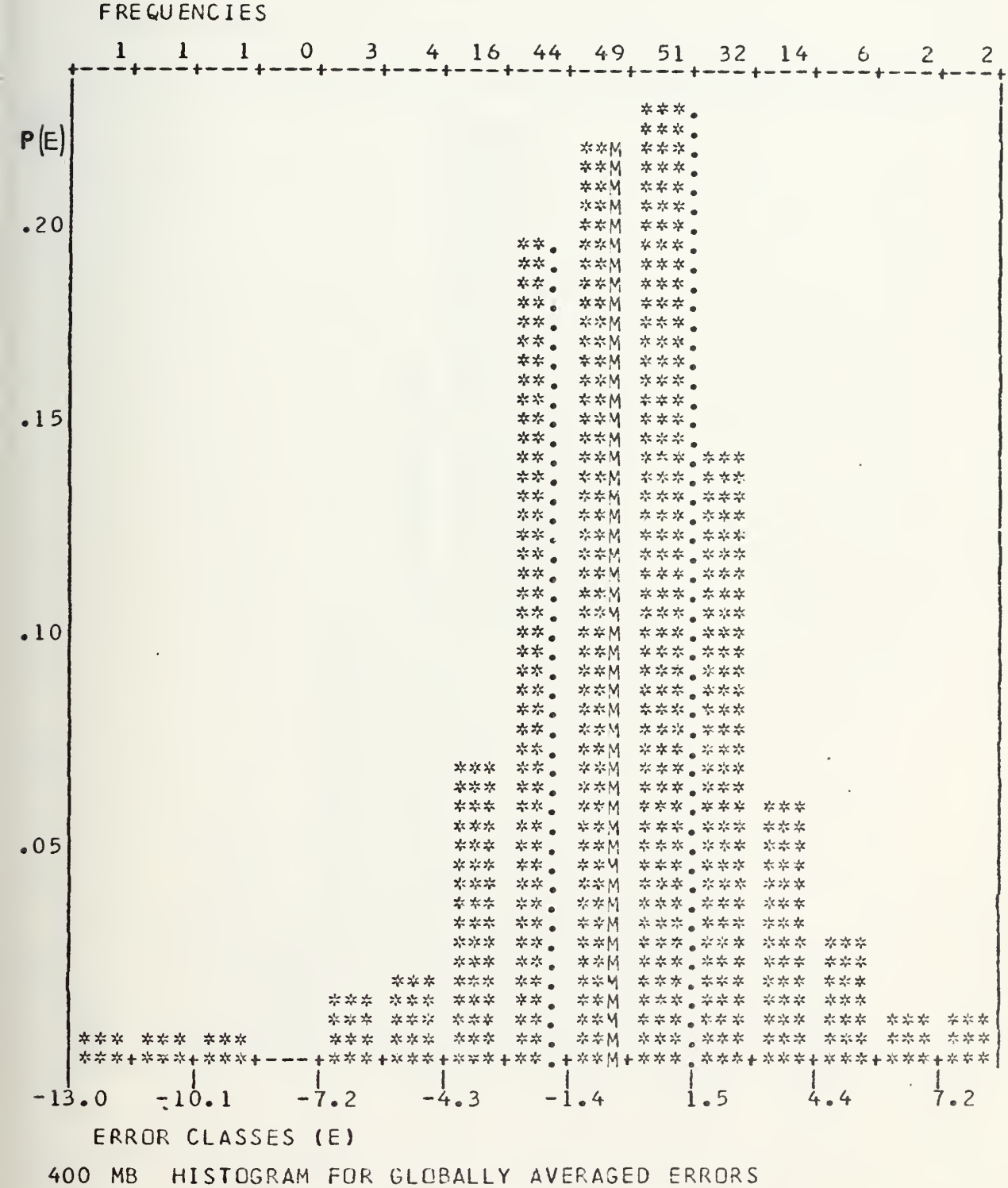
Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 227.



500 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX A-5

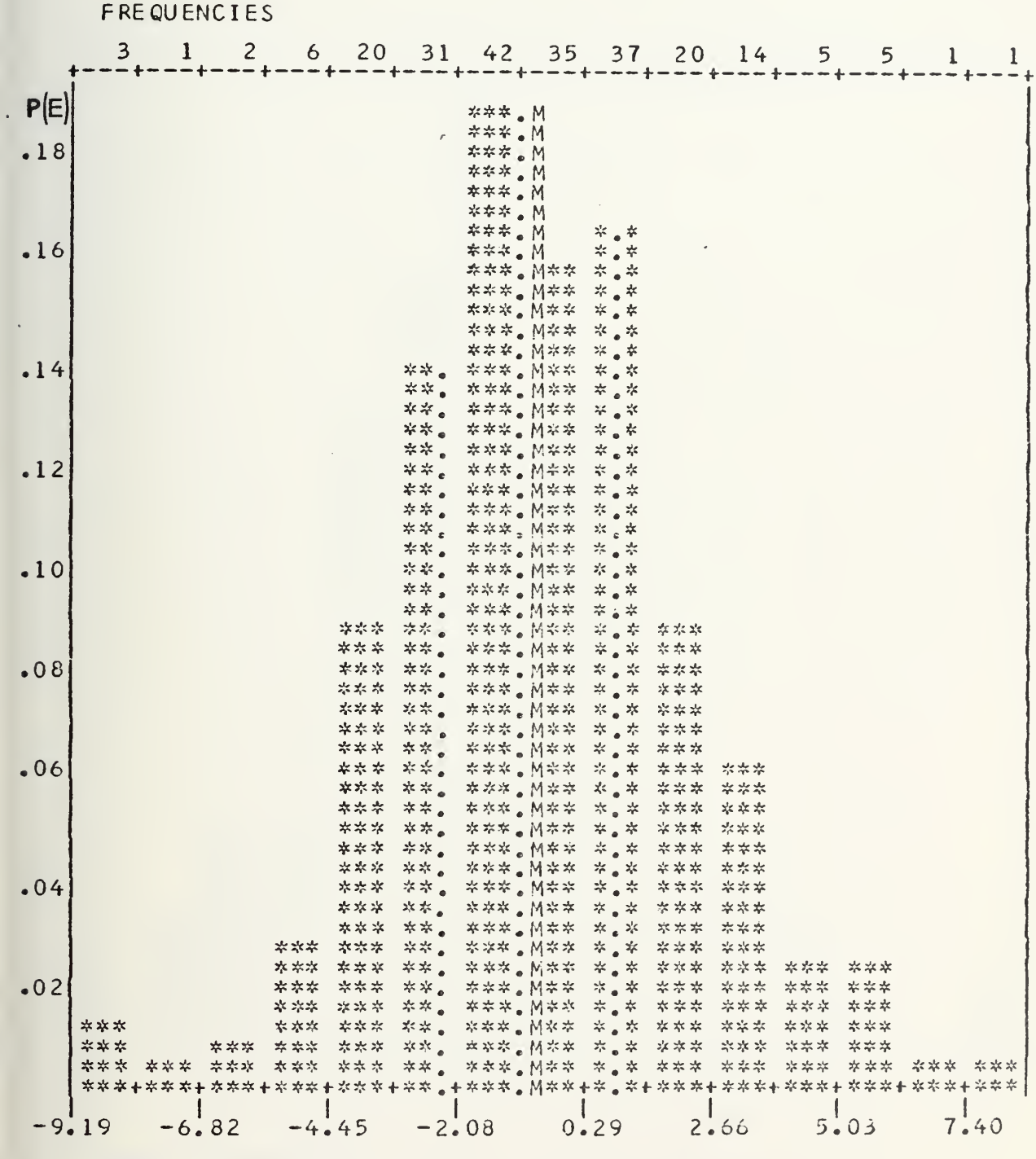
Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 226.



400 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX A-6

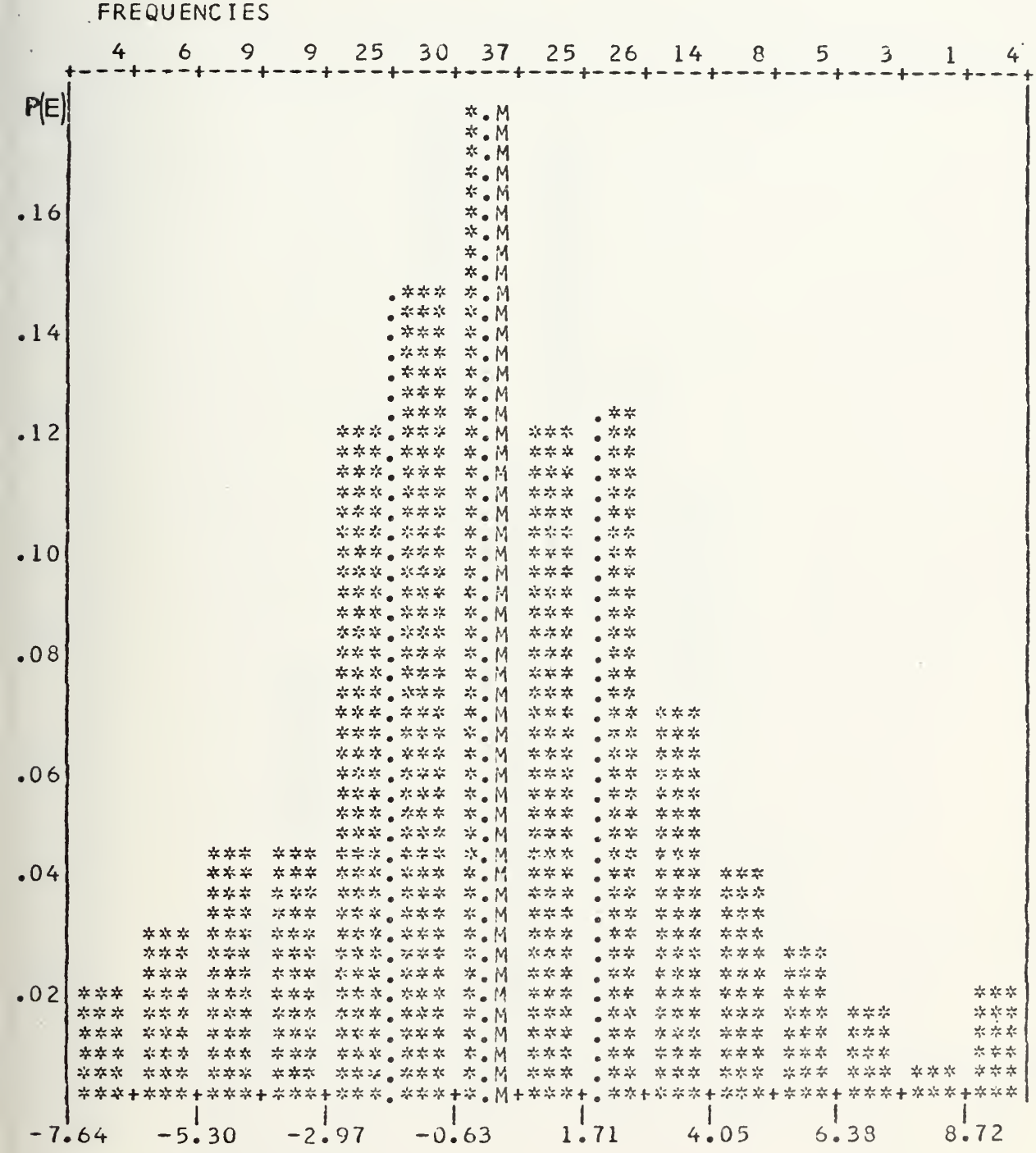
Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 223.



300 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX A-7

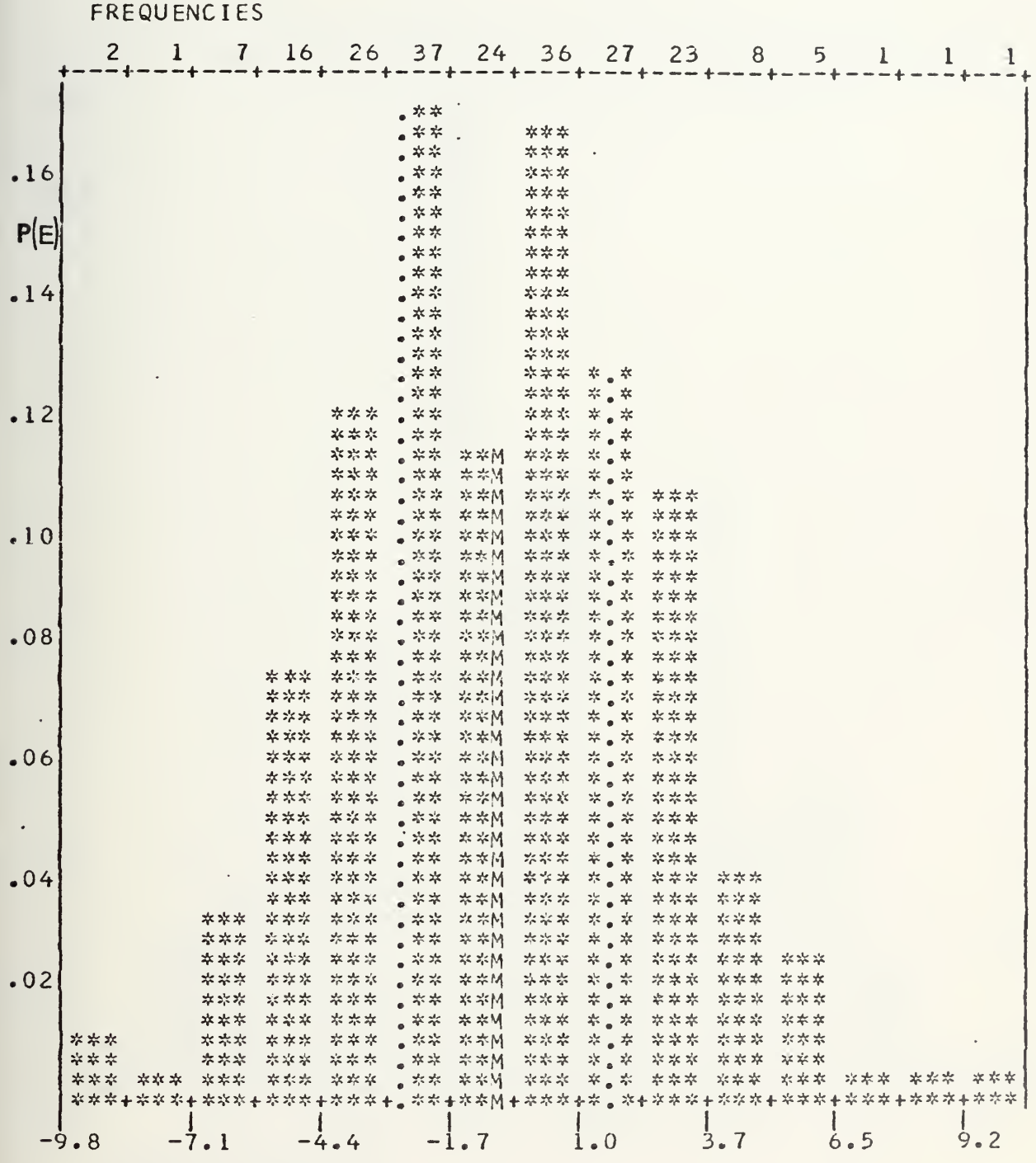
Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 206.



250 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX A-8

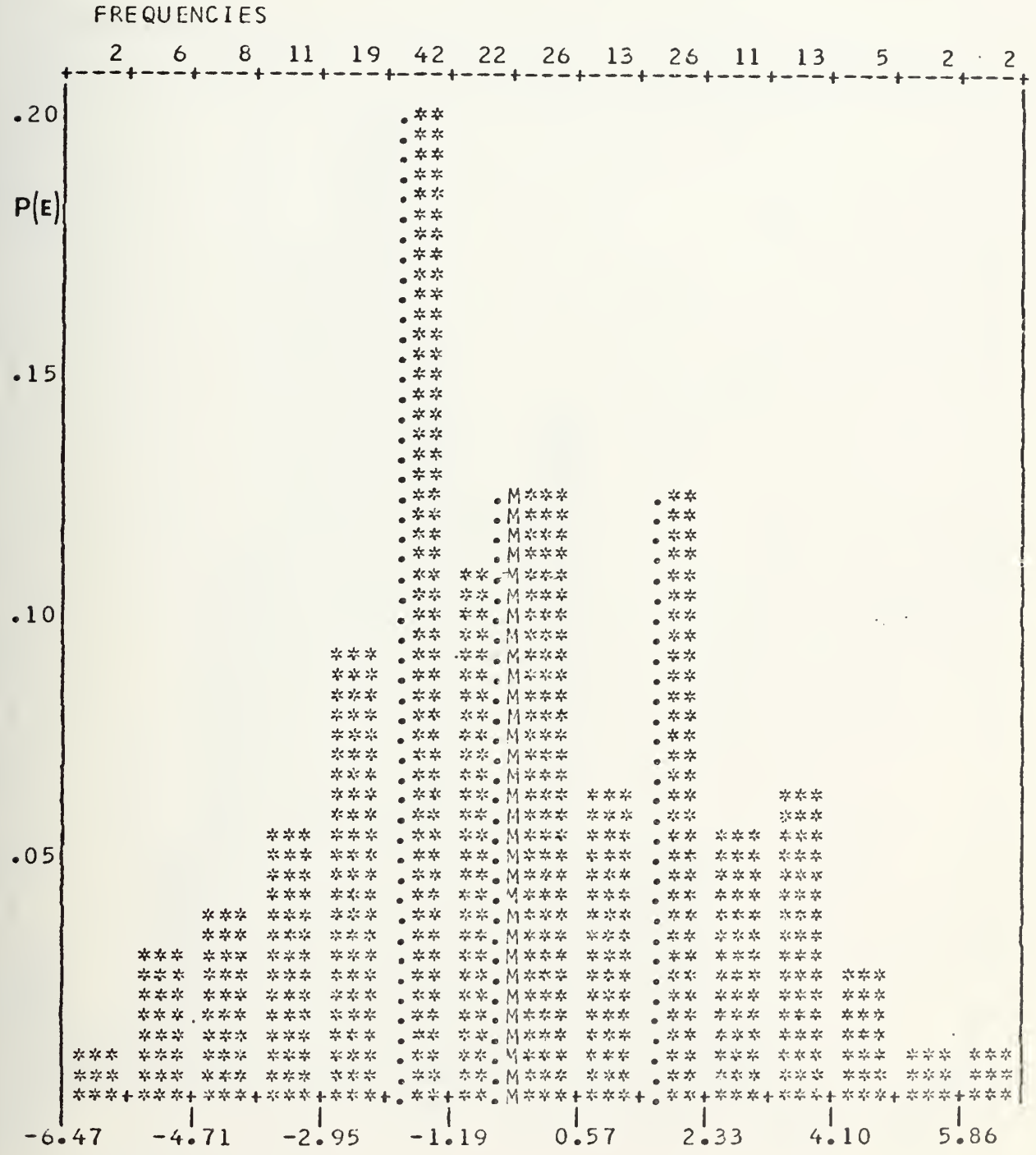
Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 215.



200 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX A-9

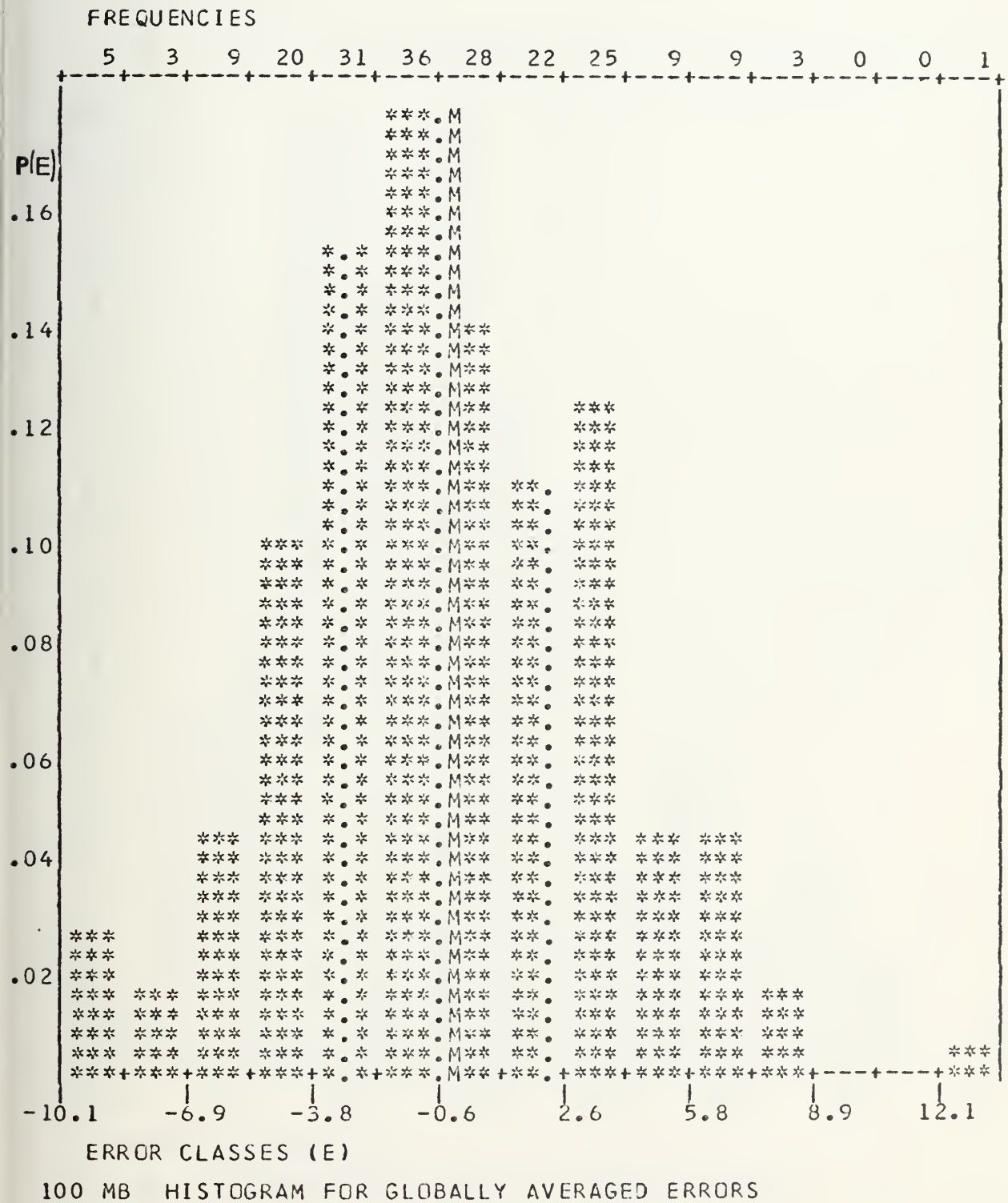
Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 208.



150 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX A-10

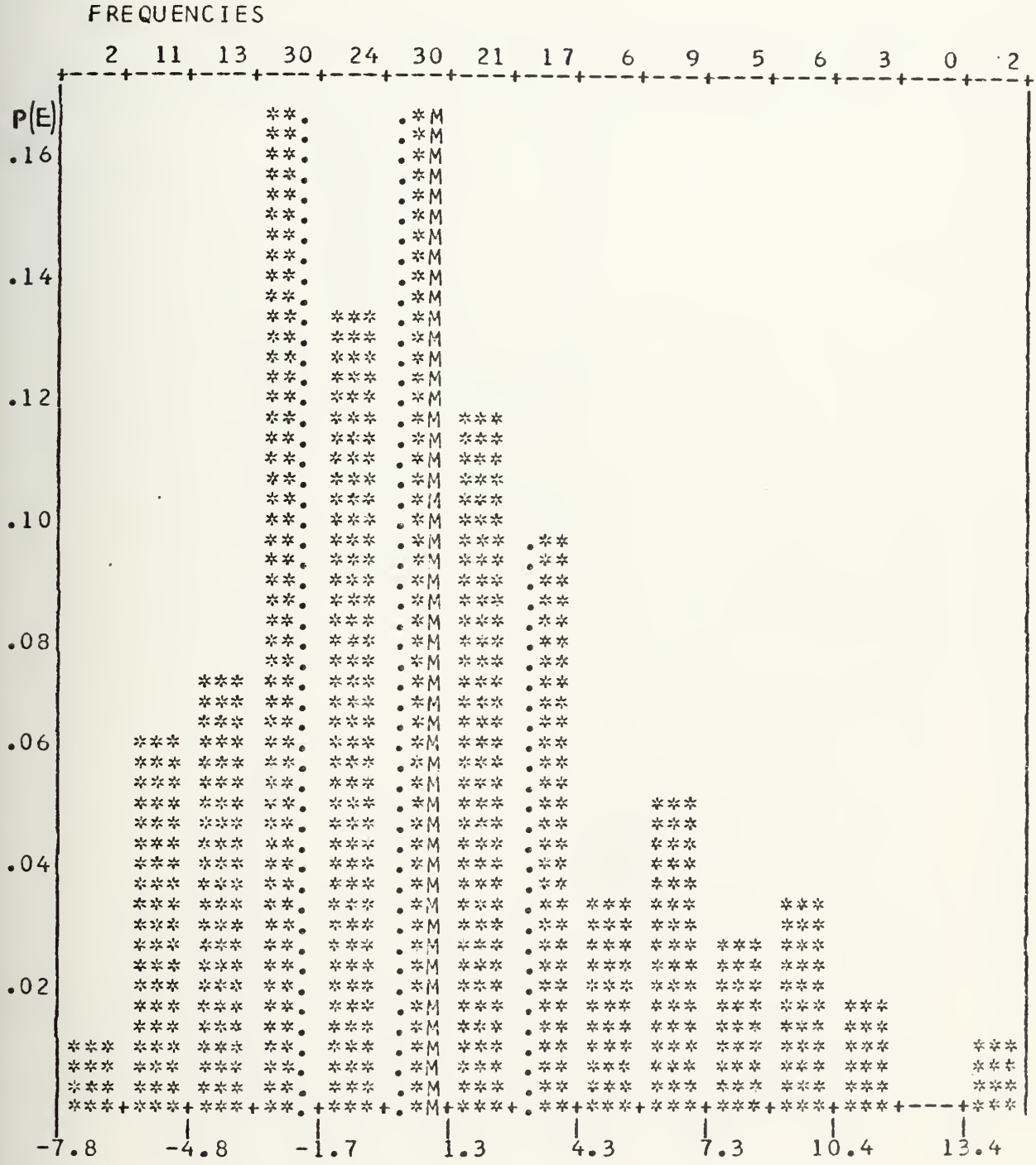
Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 179.



100 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX A-11

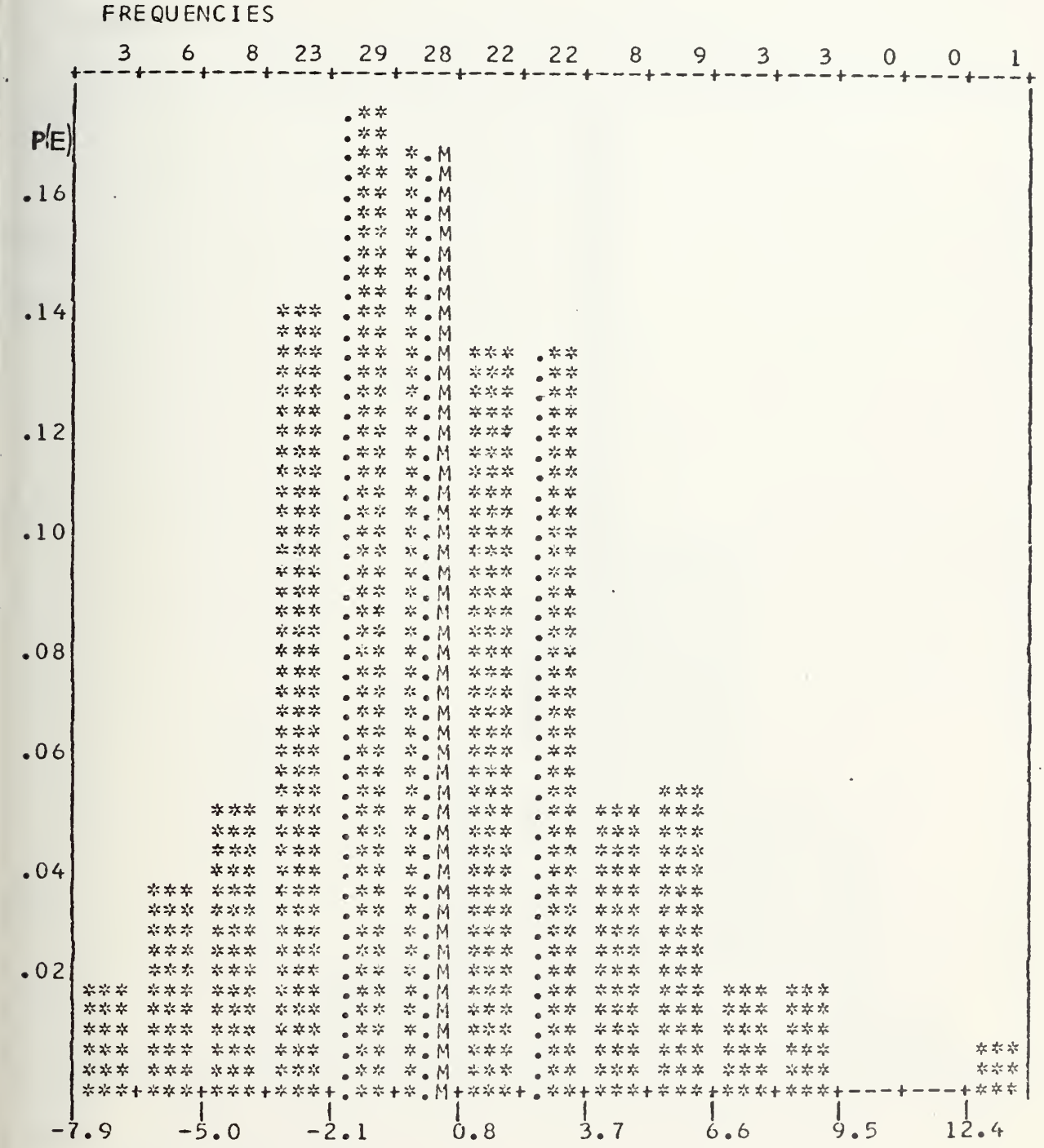
Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 179.



70 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX A-12

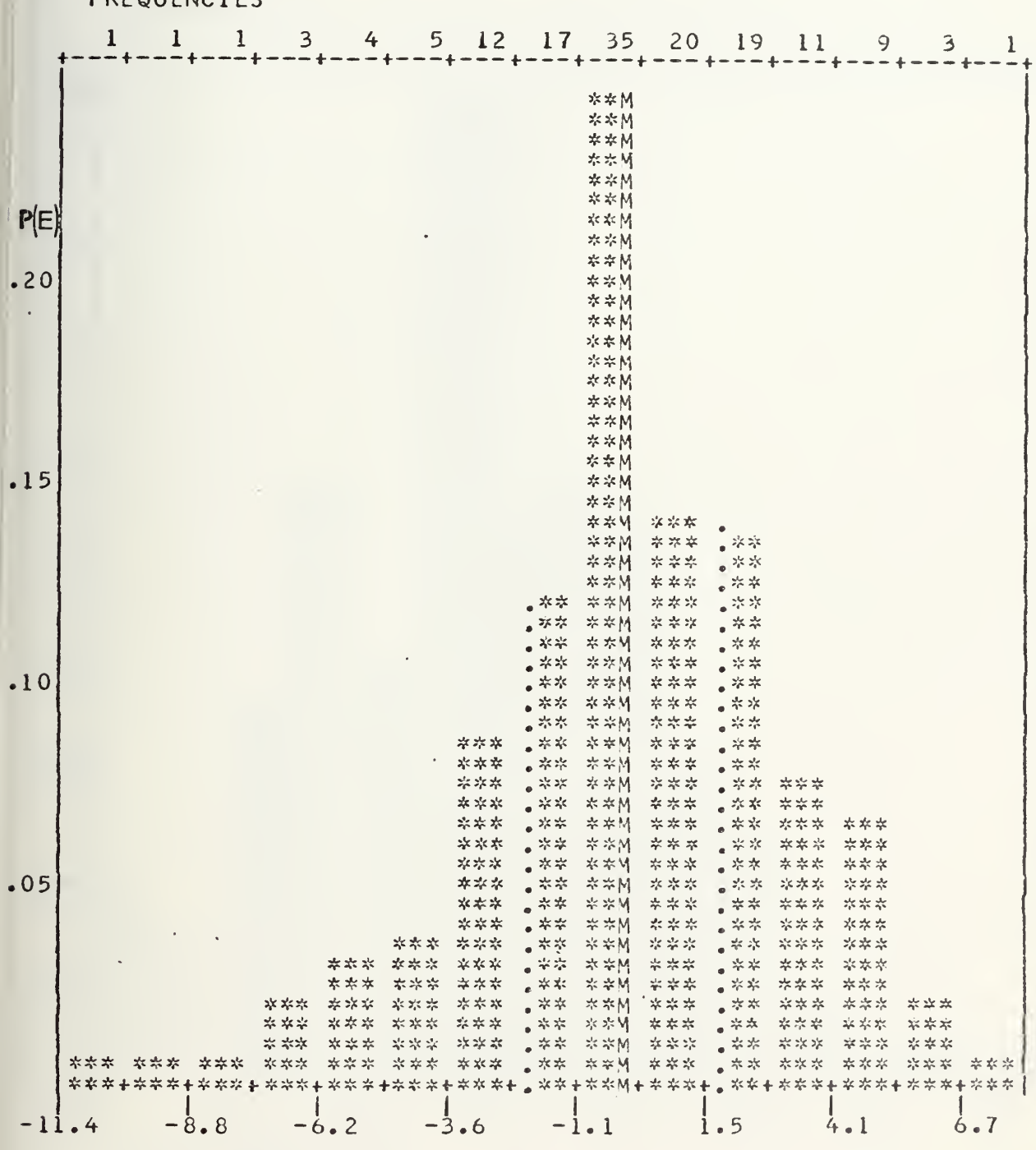
Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 142.



50 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX A-13

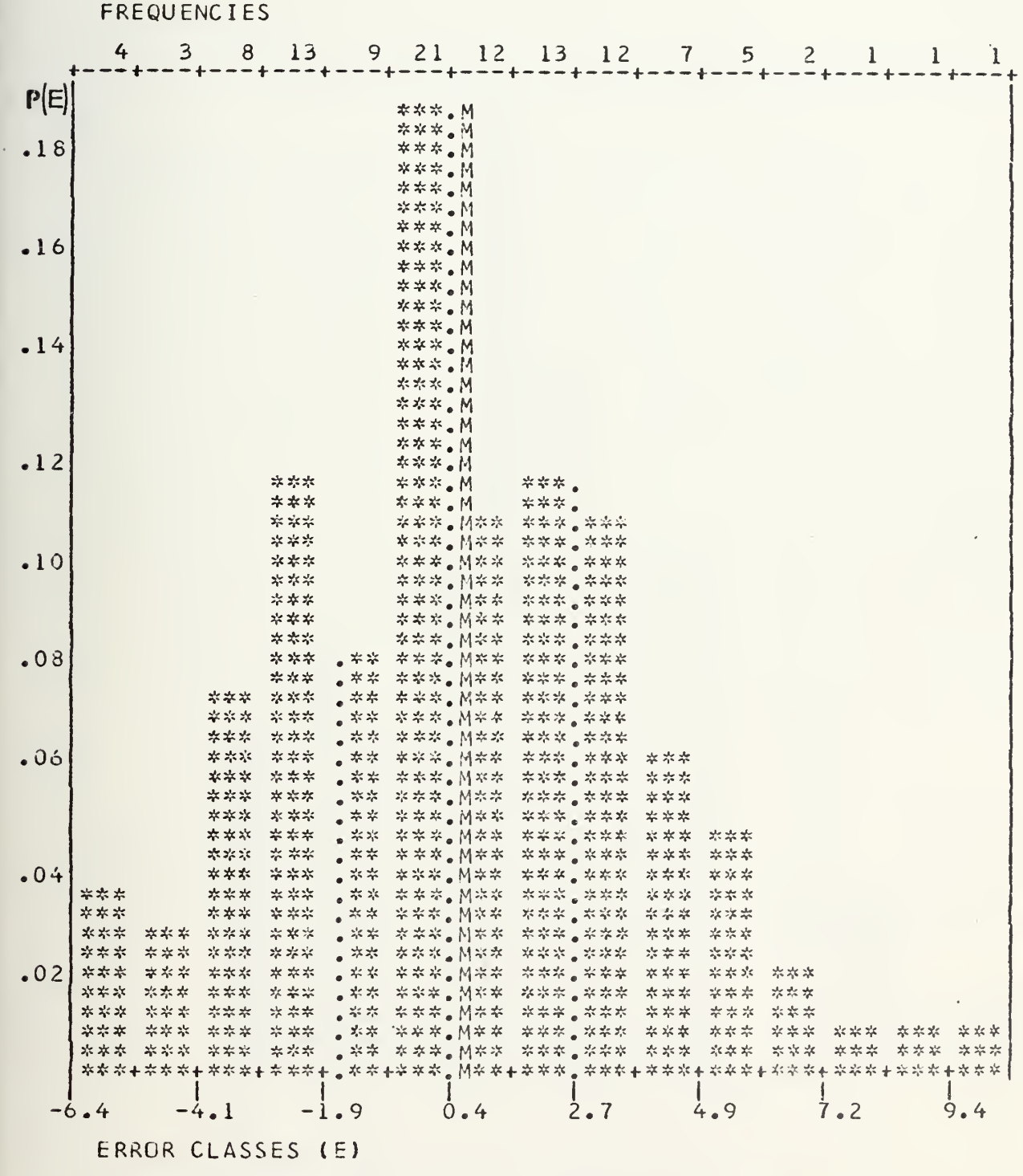
Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 142.



30 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX A-14

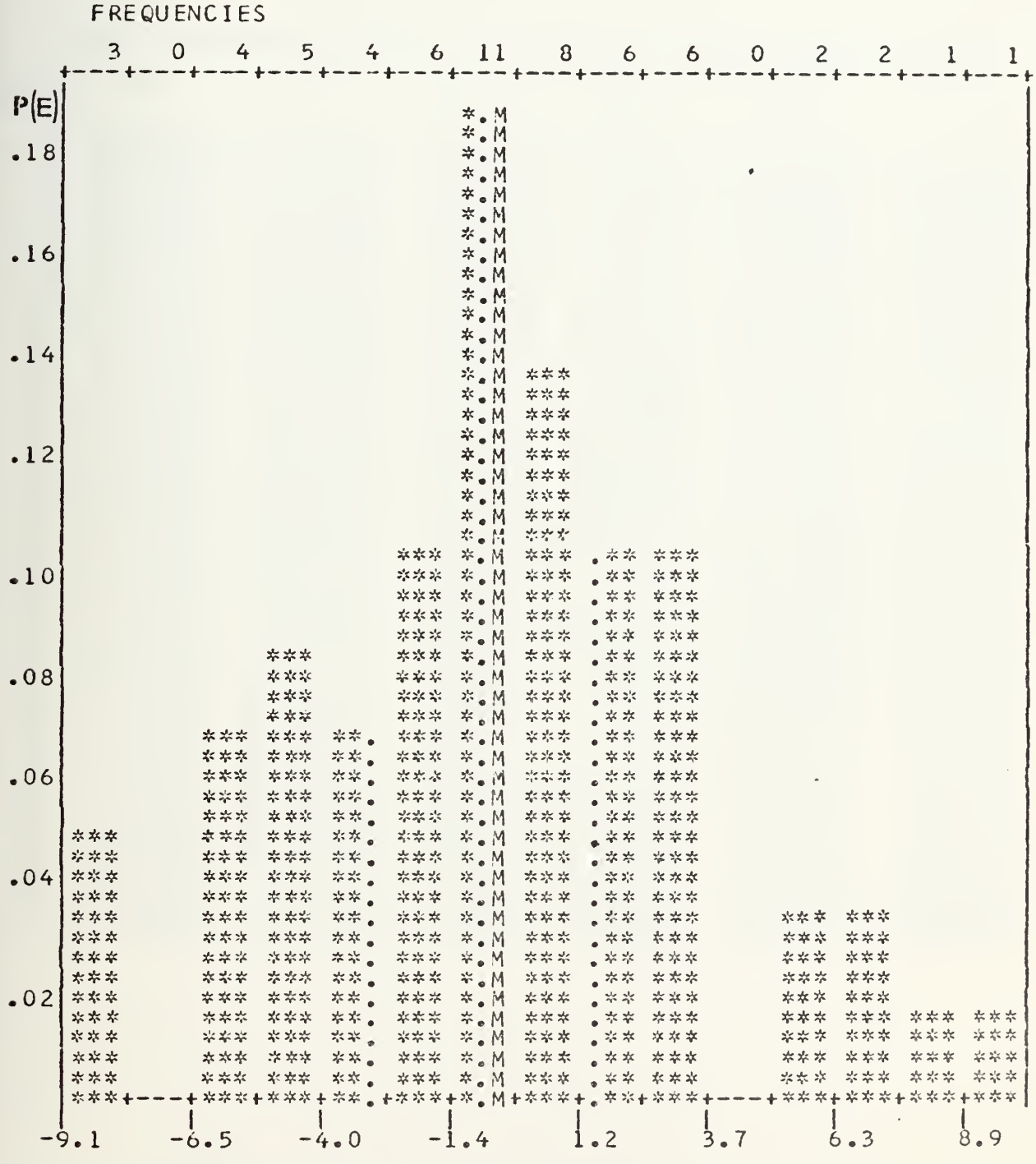
Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 112.



20 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX A-15

Histogram of the globally averaged errors showing probability distribution [P(E)] of the occurrence of the errors, the actual error frequencies in the error class E (marked along the top), the Mean (M), and the Quartiles (·), for sample size 59.



10 MB HISTOGRAM FOR GLOBALLY AVERAGED ERRORS

APPENDIX B

OZONE TRANSMITTANCES FOR THE SIX VTPR CLEAR-COLUMN CHANNELS

LEVEL	CHAN 1	CHAN 2	CHAN 3	CHAN 4	CHAN 5	CHAN 6
1	0.999992	0.999987	0.999986	0.999987	0.999991	0.999992
2	0.999982	0.999974	0.999972	0.999968	0.999974	0.999985
3	0.999966	0.999953	0.999949	0.999940	0.999949	0.999971
4	0.999941	0.999917	0.999914	0.999900	0.999912	0.999948
5	0.999906	0.999865	0.999866	0.999844	0.999857	0.999914
6	0.999859	0.999795	0.999804	0.999771	0.999780	0.999869
7	0.999797	0.999703	0.999725	0.999679	0.999679	0.999810
8	0.999717	0.999586	0.999626	0.999565	0.999551	0.999734
9	0.999618	0.999440	0.999504	0.999425	0.999392	0.999640
10	0.999497	0.999263	0.999358	0.999253	0.999198	0.999525
11	0.999352	0.999051	0.999183	0.999059	0.998967	0.999386
12	0.999182	0.998802	0.998979	0.998826	0.998694	0.999223
13	0.998982	0.998510	0.998742	0.998554	0.998375	0.999032
14	0.998748	0.998172	0.998466	0.998239	0.998006	0.998810
15	0.998476	0.997781	0.998148	0.997874	0.997579	0.998553
16	0.998162	0.997333	0.997783	0.997453	0.997092	0.998258
17	0.997801	0.996823	0.997365	0.996973	0.996537	0.997922
18	0.997392	0.996249	0.996892	0.996429	0.995914	0.997543
19	0.996937	0.995611	0.996361	0.995823	0.995224	0.997121
20	0.996440	0.994915	0.995773	0.995156	0.994470	0.996657
21	0.995905	0.994163	0.995124	0.994430	0.993656	0.996152
22	0.995331	0.993353	0.994415	0.993643	0.992781	0.995606
23	0.994703	0.992469	0.993645	0.992783	0.991827	0.995012
24	0.993998	0.991490	0.992812	0.991834	0.990771	0.994364
25	0.993196	0.990395	0.991916	0.990779	0.989591	0.993655
26	0.992294	0.989178	0.990952	0.989614	0.988283	0.992883
27	0.991320	0.987867	0.989911	0.988352	0.986872	0.992050
28	0.990306	0.986489	0.988781	0.987012	0.985391	0.991162
29	0.989287	0.985076	0.987552	0.985610	0.983869	0.990224
30	0.988294	0.983657	0.986212	0.984165	0.982333	0.989240
31	0.987361	0.982262	0.984751	0.982693	0.980829	0.988214
32	0.986509	0.980911	0.983165	0.981209	0.979362	0.987153
33	0.985736	0.979606	0.981446	0.979717	0.977941	0.986062
34	0.985037	0.978345	0.979671	0.978222	0.976565	0.984945
35	0.984405	0.977129	0.977793	0.976728	0.975231	0.983810
36	0.983835	0.975954	0.975849	0.975240	0.973939	0.982662
37	0.983323	0.974821	0.973853	0.973761	0.972689	0.981507
38	0.982861	0.973728	0.971821	0.972295	0.971479	0.980350
39	0.982445	0.972674	0.969768	0.970848	0.970309	0.979197
40	0.982069	0.971658	0.967708	0.969423	0.969177	0.978054

41	0.981727	0.970676	0.965657	0.958025	0.868082	0.975925
42	0.981414	0.969733	0.963631	0.956657	0.957024	0.975820
43	0.981124	0.968822	0.961643	0.955325	0.956001	0.974742
44	0.980852	0.967945	0.959710	0.954032	0.955013	0.973696
45	0.980592	0.967099	0.957846	0.952782	0.954059	0.972688
46	0.980338	0.966284	0.956067	0.951580	0.953137	0.971725
47	0.980086	0.965498	0.954388	0.950430	0.952247	0.970813
48	0.979828	0.964740	0.952823	0.949336	0.951388	0.969955
49	0.979561	0.964010	0.951389	0.948303	0.950558	0.969160
50	0.979277	0.963305	0.950100	0.947335	0.949758	0.968433
51	0.978972	0.962625	0.948970	0.946436	0.948985	0.967777
52	0.978647	0.961970	0.947998	0.945605	0.948241	0.967195
53	0.978307	0.961342	0.947171	0.944841	0.947528	0.966679
54	0.977957	0.960744	0.946474	0.944140	0.946848	0.966226
55	0.977603	0.960175	0.945893	0.943500	0.946203	0.965828
56	0.977250	0.959640	0.945414	0.942917	0.945595	0.965482
57	0.976905	0.959139	0.945022	0.942389	0.945027	0.965182
58	0.976572	0.958674	0.944704	0.941912	0.944500	0.964922
59	0.976256	0.958247	0.944446	0.941485	0.944016	0.964697
60	0.975965	0.957860	0.944232	0.941103	0.943578	0.964502
61	0.975702	0.957514	0.944050	0.940764	0.943188	0.964331
62	0.975474	0.957212	0.943884	0.940466	0.942848	0.964180
63	0.975285	0.956955	0.943772	0.940204	0.942559	0.964042
64	0.975131	0.956738	0.943562	0.939976	0.942316	0.963915
65	0.975008	0.956555	0.943406	0.939775	0.942113	0.963802
66	0.974908	0.956400	0.943253	0.939599	0.941942	0.963696
67	0.974828	0.956268	0.943105	0.939443	0.941796	0.963599
68	0.974760	0.956153	0.942962	0.939302	0.941670	0.963509
69	0.974700	0.956049	0.942827	0.939173	0.941556	0.963425
70	0.974642	0.955949	0.942699	0.939049	0.941447	0.963346
71	0.974581	0.955849	0.942579	0.938929	0.941337	0.963270
72	0.974517	0.955748	0.942467	0.938811	0.941226	0.963197
73	0.974450	0.955646	0.942362	0.938693	0.941113	0.963126
74	0.974380	0.955543	0.942263	0.938578	0.940999	0.963058
75	0.974310	0.955440	0.942169	0.938463	0.940884	0.962991
76	0.974238	0.955335	0.942079	0.938350	0.940767	0.962925
77	0.974165	0.955230	0.941992	0.938237	0.940650	0.962860
78	0.974093	0.955124	0.941908	0.938125	0.940532	0.962795
79	0.974022	0.955019	0.941824	0.938014	0.940413	0.962732
80	0.973953	0.954913	0.941741	0.937903	0.940294	0.962667

81	0.973885	0.954807	0.941657	0.947792	0.950174	0.962602
82	0.973820	0.954701	0.941572	0.947680	0.950055	0.962535
83	0.973758	0.954595	0.941485	0.947569	0.949935	0.962468
84	0.973698	0.954488	0.941395	0.947456	0.949814	0.962398
85	0.973638	0.954380	0.941303	0.947343	0.949691	0.962327
86	0.973577	0.954269	0.941209	0.947227	0.949566	0.962253
87	0.973515	0.954156	0.941112	0.947110	0.949438	0.962177
88	0.973451	0.954039	0.941012	0.946990	0.949306	0.962098
89	0.973383	0.953917	0.940910	0.946867	0.949170	0.962017
90	0.973311	0.953790	0.940804	0.946741	0.949029	0.961932
91	0.973233	0.953658	0.940696	0.946611	0.948881	0.961844
92	0.973150	0.953520	0.940584	0.946478	0.948729	0.961753
93	0.973063	0.953377	0.940470	0.946342	0.948572	0.961660
94	0.972972	0.953231	0.940354	0.946203	0.948411	0.961564
95	0.972878	0.953080	0.940236	0.946062	0.948246	0.961465
96	0.972781	0.952927	0.940116	0.945919	0.948079	0.961367
97	0.972681	0.952772	0.939995	0.945774	0.947909	0.961265
98	0.972580	0.952614	0.939873	0.945628	0.947737	0.961164
99	0.972478	0.952456	0.939751	0.945482	0.947564	0.961064
100	0.972376	0.952297	0.939628	0.945335	0.947391	0.960958

U. S. STANDARD ATMOSPHERE SUPPLEMENTS

LEVEL	15N ANN	30N JUL	30N JAN	45N JUL	45N JAN	60N JUL	60N JAN	75N JUL	75N JAN
1	184.50	180.30	191.40	174.20	210.20	171.20	232.10	174.20	224.10
2	190.90	187.00	197.50	180.10	215.30	175.00	236.00	178.00	228.00
3	196.20	192.60	203.10	186.00	219.10	182.10	238.00	185.10	230.80
4	200.90	197.10	206.70	191.50	222.00	187.80	241.00	190.80	233.00
5	204.80	201.80	210.90	196.20	224.50	192.70	242.90	195.70	234.90
6	210.90	208.10	215.70	204.10	228.50	200.40	245.70	203.40	237.70
7	215.60	213.00	220.00	210.00	231.70	206.70	246.80	209.70	238.80
8	219.60	217.60	224.20	215.20	234.30	211.90	247.40	214.90	239.40
9	223.00	221.30	227.10	219.10	236.40	216.40	248.00	219.40	240.00
10	226.60	225.50	231.10	224.60	239.40	222.10	248.70	225.10	240.70
11	228.90	227.30	232.20	226.10	240.20	225.00	248.90	228.00	240.90
12	232.10	231.00	234.40	230.60	242.70	227.30	249.40	230.30	241.40
13	242.00	240.50	243.40	243.90	247.70	240.40	250.80	243.40	242.80
14	248.90	248.10	250.00	251.70	251.80	250.10	253.70	253.10	245.70
15	254.50	254.80	254.40	255.90	255.10	257.80	255.70	260.80	248.70
16	257.00	258.40	257.30	259.10	257.80	263.90	259.10	266.90	251.10
17	261.30	262.40	261.40	264.40	262.40	269.30	260.20	272.30	252.20
18	264.80	266.00	265.00	268.80	265.20	272.80	260.20	275.80	252.20
19	267.60	268.90	267.80	272.40	265.60	275.80	258.40	278.80	250.40
20	269.80	271.30	269.10	275.00	265.60	277.20	255.40	280.20	247.40
21	270.20	272.20	269.20	275.70	265.60	277.20	251.90	280.20	243.90
22	270.20	272.20	269.20	275.70	265.40	277.20	250.50	280.20	242.50
23	270.20	272.20	269.20	275.70	264.50	277.20	249.00	280.20	241.00
24	265.30	267.30	262.20	272.60	254.90	275.20	241.60	278.20	233.60
25	260.80	262.50	258.40	267.00	248.30	272.70	235.60	275.70	228.60
26	257.00	259.00	254.00	262.60	243.40	268.90	232.80	271.90	224.80
27	254.10	255.30	250.30	259.50	239.10	264.90	229.70	267.90	221.70
28	249.70	250.40	245.40	253.90	233.10	258.30	224.80	261.30	216.80
29	246.00	246.50	242.00	249.80	228.50	253.30	221.40	256.30	213.40
30	243.10	243.10	238.50	246.40	224.80	249.40	219.40	252.40	211.40
31	240.50	240.70	236.20	243.90	221.70	246.40	218.30	249.40	210.30
32	237.90	238.50	233.10	240.50	218.70	241.70	217.20	244.70	209.20
33	237.00	235.70	232.20	239.20	218.40	240.60	215.80	243.60	208.80
34	235.00	234.10	230.80	237.50	217.90	238.50	215.10	241.50	207.60
35	229.00	229.50	225.40	231.70	215.90	234.30	213.70	237.20	207.60
36	224.20	225.80	221.40	227.50	215.20	231.30	211.80	234.70	207.60
37	221.60	222.40	218.70	225.60	215.20	229.10	211.60	232.80	207.60
38	219.20	220.30	216.70	224.40	215.20	227.30	212.20	231.40	207.60
39	214.80	216.40	212.80	222.10	215.20	225.20	213.40	230.20	207.60
40	209.00	213.90	209.50	220.30	215.20	225.20	214.20	230.20	207.70

41	204.30	211.40	206.20	219.00	215.20	225.20	214.90	230.20	208.20
42	200.20	209.20	204.30	217.80	215.50	225.20	215.40	230.20	208.90
43	197.20	206.40	203.20	216.50	215.10	225.20	215.20	230.20	209.80
44	195.50	205.70	203.30	215.90	216.30	225.20	215.40	230.20	210.10
45	196.10	204.50	205.50	215.70	216.60	225.20	215.80	230.20	210.80
46	200.70	208.20	211.50	215.70	217.90	225.20	217.20	228.40	212.60
47	209.40	221.00	216.00	221.90	218.80	225.20	217.20	228.40	213.90
48	220.60	231.40	224.80	229.30	219.60	225.70	217.20	229.00	214.60
49	239.00	240.40	233.00	238.10	225.80	230.70	218.50	229.10	216.70
50	254.90	255.30	246.00	253.00	237.60	244.40	229.10	241.70	225.00
51	264.10	266.80	256.80	262.40	247.30	256.00	239.60	252.10	234.10
52	273.60	274.70	266.20	272.00	255.00	264.50	248.20	261.00	241.10
53	282.70	282.20	274.30	278.80	261.90	270.90	253.40	268.50	247.10
54	290.50	290.30	282.60	287.30	267.10	279.80	259.10	274.60	251.90
55	293.40	293.30	284.00	289.50	268.70	281.90	259.00	275.70	251.80
56	299.10	300.60	286.30	293.80	271.60	286.80	257.30	278.40	249.40

TEST AND EVALUATION
OF A VTPR RETRIEVAL SYSTEM
FROM CLEAR-COLUMN NOAA 2 RADIANCES

LCDR HARRY M. DYCK JR.
NAVAL POSTGRADUATE SCHOOL
MARCH 1975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      COMMON/WORK/VTPR(2,100),A1(100,6),A2(100,6),A3(100,6),TAU(100,6)   MAIN   5
      COMMON/FIRST/STATM(10,56),FG(2,56)                                 MAIN  10
      COMMON/SCND/TSTD(100),A(6)                                         MAIN  15
      COMMON/THRD/D1(6),D4(6),D5(6),D10(6),D12(6)                        MAIN  20
      COMMON/FOUR/DIM(100),TAUW(100,8),CW(8,14),U(100),AA(14),PATH,NP,   MAIN  25
     1W(100)                                                             MAIN  30
      DIMENSION REPORT(2,15),PREF(56)                                    MAIN  35
      DIMENSION CREG(40,11),TBAR(11),WBAR(40),WS(11)                     MAIN  40
      DIMENSION LEVEL(11),SAT(11)                                        MAIN  45
      DIMENSION B(33,6),BB(100,6),BMEAN(33,6),RADTOT(6)                  MAIN  50
      DIMENSION CHAN(6),RADOBS(6),DTAUW(33,6),T(15),T33(33)              MAIN  55
      DIMENSION DDTAUW(100,6)                                            MAIN  60
      DIMENSION AT(15)                                                   MAIN  65
      DIMENSION TERROR(4,235)                                            MAIN  70
      DIMENSION ERROR(4,15,233)                                          MAIN  75
      DIMENSION TROR(235)                                                MAIN  80
      DIMENSION VT(15),VERROR(4,15,233),TVROR(4,234),TVOR(235)           MAIN  85
      DIMENSION OZTAU(100,6)                                             MAIN  90
      DIMENSION AVCHAN(100)                                              MAIN  95
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CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCMAIN 100
C                                                                              MAIN 105
C     THIS PART OF THE PROGRAM READS IN THE DATA TO BE USED                    MAIN 110
C                                                                              MAIN 115
C     PREF IS PRESSURE AT 56 LEVELS                                            MAIN 120
C                                                                              MAIN 125
C     REPORT(1,K) IS PRESSURE AT 15 LEVELS                                     MAIN 130
C                                                                              MAIN 135
C     STATM IS CLIMATOLOGY STANDARD ATMOSPHERE FOR VARIOUS LATITUDES ANDMAIN 140
C     SEASONS                                                                  MAIN 145
C                                                                              MAIN 150
C     TSTD(N) IS 56 LEVEL STANDARD TEMPERATURES                                MAIN 155
C                                                                              MAIN 160
C     A(N) ARE COEFFICIENTS FOR CO2 TRANSMITTANCE                              MAIN 165
C                                                                              MAIN 170
C     D1 THRU D12 ARE COEFICIENTS FOR ZENITH ANGLE CORRECTION                  MAIN 175
C                                                                              MAIN 180
C     A1, A2, AND A3 ARE COEFFICIENTS FOR CO2 TRANSMITTANCE CALCULATION        MAIN 185
C                                                                              MAIN 190
C     CREG, TBAR, WBAR CW, AND LEVEL ARE COEFFICIENTS FOR WATER VAPOR          MAIN 195
C     CALCULATION                                                              MAIN 200
C                                                                              MAIN 205
C     CHAN IS THE WAVE NUMBERS OF CHANNELS 1,2,...,6                           MAIN 210
C                                                                              MAIN 215
C     NBAR IS THE NUMBER OF BARS TO BE DRAWN IN THE HISTOGRAMS                 MAIN 220
C                                                                              MAIN 225
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCMAIN 230
C                                                                              MAIN 235
      NBAR = 15                                                                MAIN 240
      NP = 100                                                                 MAIN 245
      C1 = 1.19061E-05                                                         MAIN 250
      C2 = 1.43868                                                             MAIN 255
      DO 115 I=1,4                                                             MAIN 265
C                                                                              MAIN 270
      DO 110 K=1,15                                                            MAIN 275
C                                                                              MAIN 280
C                                                                              MAIN 285
      DO 105 J=1,233                                                           MAIN 290
      ERROR(I,K,J) = 0.0                                                       MAIN 295
  105 CONTINUE                                                                 MAIN 300
C                                                                              MAIN 305
C                                                                              MAIN 310
  110 CONTINUE                                                                 MAIN 315
C                                                                              MAIN 320
  115 CONTINUE                                                                 MAIN 325
C                                                                              MAIN 330
C                                                                              MAIN 335
      READ (5,440) (PREF(I),I=1,56)                                            MAIN 340
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```
      READ (5,425) (REPORT(1,K),K=1,15)                                 MAIN 345
C                                                                       MAIN 350
C                                                                       MAIN 355
      DO 120 I=2,10                                                     MAIN 360
      READ (5,435) (STATM(I,J),J=1,14)                                  MAIN 365
      READ (5,435) (STATM(I,J),J=15,28)                                 MAIN 370
      READ (5,435) (STATM(I,J),J=29,42)                                 MAIN 375
      READ (5,435) (STATM(I,J),J=43,56)                                 MAIN 380
  120 CONTINUE                                                          MAIN 385
C                                                                       MAIN 390
C                                                                       MAIN 405
      DO 125 I=1,12                                                     MAIN 410
      J = I*8                                                           MAIN 415
      K = J-7                                                           MAIN 420
      READ (5,450) (TSTD(N),N=K,J)                                      MAIN 425
  125 CONTINUE                                                          MAIN 430
C                                                                       MAIN 435
C                                                                       MAIN 440
      READ (5,450) (TSTD(N),N=97,100)                                   MAIN 445
      READ (5,450) (A(N),N=1,6)                                         MAIN 450
C                                                                       MAIN 455
C                                                                       MAIN 460
      DO 145 I=1,6                                                      MAIN 465
C                                                                       MAIN 470
C                                                                       MAIN 475
      DO 130 L=1,10                                                     MAIN 480
      KK = 10*L                                                         MAIN 485
      K = KK-9                                                          MAIN 490
      READ (5,445) (A1(N,I),N=K,KK)                                     MAIN 495
  130 CONTINUE                                                          MAIN 500
C                                                                       MAIN 505
C                                                                       MAIN 520
      DO 135 L=1,17                                                     MAIN 525
      KK = 6*L                                                          MAIN 530
      K = KK-5                                                          MAIN 535
      IF (L.EQ.17) KK = 100                                             MAIN 540
      READ (5,455) (A2(N,I),N=K,KK)                                     MAIN 545
  135 CONTINUE                                                          MAIN 550
C                                                                       MAIN 555
C                                                                       MAIN 570
      DO 140 L=1,17                                                     MAIN 575
      KK = 6*L                                                          MAIN 580
      K = KK-5                                                          MAIN 585
      IF (L.EQ.17) KK = 100                                             MAIN 590
      READ (5,455) (A3(N,I),N=K,KK)                                     MAIN 595
  140 CONTINUE                                                          MAIN 600
C                                                                       MAIN 605
C                                                                       MAIN 610
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  145 CONTINUE                                                          MAIN  615
C                                                                       MAIN  620
C                                                                       MAIN  625
      READ (5,460) D1                                                   MAIN  630
      READ (5,460) D4                                                   MAIN  635
      READ (5,460) D5                                                   MAIN  640
      READ (5,460) D10                                                  MAIN  645
      READ (5,460) D12                                                  MAIN  650
      READ (5,470) ((CREG(M,L),L=1,11),M=1,40)                          MAIN  655
      READ (5,480) (TBAR(K),K=1,11)                                     MAIN  660
      READ (5,480) (WBAR(K),K=1,40)                                     MAIN  665
      READ (5,475) (LEVEL(I),I=1,11)                                    MAIN  670
C                                                                       MAIN  675
      DO 150 I=1,6                                                      MAIN  680
      READ (5,395) (OZTAU(J,I),J=1,100)                                 MAIN  685
  150 CONTINUE                                                          MAIN  690
C                                                                       MAIN  695
C                                                                       MAIN  730
      DO 160 I=1,8                                                      MAIN  735
      READ (5,485) (CW(I,N),N=1,7)                                      MAIN  740
      READ (5,485) (CW(I,N),N=8,14)                                     MAIN  745
  160 CONTINUE                                                          MAIN  750
C                                                                       MAIN  755
C                                                                       MAIN  760
      READ (5,490) (CHAN(N),N=1,6)                                      MAIN  765
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCMAIN  770
C                                                                       MAIN  775
C       LOOP HERE TO DO MORE SOUNDINGS                                  MAIN  780
C                                                                       MAIN  785
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCMAIN  790
C                                                                       MAIN  795
C                                                                       MAIN  800
      DO 365 LOOP=1,250                                                 MAIN  805
      WRITE (6,405)                                                     MAIN  810
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCMAIN  815
C                                                                       MAIN  820
C     READ IN THE VARIABLES USED IN EACH SOUNDING                       MAIN  825
C                                                                       MAIN  830
C     ALAT IS THE STATION LATITUDE                                      MAIN  835
C                                                                       MAIN  840
C     PATH IS THE ZENITH ANGLE                                          MAIN  845
C                                                                       MAIN  850
C     REPORT(2,K) IS THE FIRST GUESS TEMPERATURE                        MAIN  855
C                                                                       MAIN  860
C     TSFC IS THE SEA SURFACE TEMPERATURE                               MAIN  865
C                                                                       MAIN  870
C     RADOBS IS THE CLEAR COLUMN RADIANCE VALUES                        MAIN  875
C                                                                       MAIN  880
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CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCMAIN  885
      READ (5,465,END=370) ALAT                                              MAIN  890
      WRITE (6,420) LOOP                                                     MAIN  895
      IF (ALAT.LT.15.01) ALAT=15.01                                          MAIN  900
      READ (5,465) PATH                                                      MAIN  905
      READ (5,430) (REPORT(2,K),K=1,15)                                      MAIN  910
      READ (5,495) TSFC                                                      MAIN  915
      READ (5,495) (RADOBS(N),N=1,6)                                         MAIN  920
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCMAIN  925
C                                                                            MAIN  930
C     READ IN THE DATA NEEDED TO DETERMINE THE ACCURACY OF THE ANSWER        MAIN  935
C                                                                            MAIN  940
C     AT IS THE ACTUAL TEMPERATURE SOUNDING                                  MAIN  945
C                                                                            MAIN  950
C     VT IS THE TEMPERATURE DERIVED BY NESS                                  MAIN  955
C                                                                            MAIN  960
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCMAIN  965
      READ (5,430) (AT(K),K=1,15)                                            MAIN  970
      READ (5,430) (VT(K),K=1,15)                                            MAIN  975
      WRITE (6,500) PATH                                                     MAIN  980
      IF (PATH.LT.0.0001) GO TO 165                                          MAIN  985
C                                                                            MAIN  990
C     CONVERT PATH FROM DEGREES TO RADIANS                                   MAIN  995
C                                                                            MAIN1000
      PATH = 0.017453*PATH                                                   MAIN1005
C                                                                            MAIN1010
C     CONVERT PATH TO THE SECANT OF THE ZENITH ANGLE                         MAIN1015
C                                                                            MAIN1020
  165 PATH = 1./COS(PATH)                                                    MAIN1025
C                                                                            MAIN1030
C     CONVERT 15 LEVELS TO 56 LEVELS                                         MAIN1035
C                                                                            MAIN1040
C                                                                            MAIN1050
      DO 175 N=1,56                                                          MAIN1055
      STATM(1,N) = STATM(2,N)                                                MAIN1060
      FG(1,N) = PREF(N)                                                      MAIN1065
      FG(2,N) = 99.9                                                         MAIN1070
      IF (N.LT.33) GO TO 175                                                 MAIN1075
C                                                                            MAIN1080
C                                                                            MAIN1085
      DO 170 I=1,15                                                          MAIN1090
      IF (FG(1,N).EQ.REPORT(1,I)) FG(2,N)=REPORT(2,I)                        MAIN1095
  170 CONTINUE                                                               MAIN1100
C                                                                            MAIN1105
C                                                                            MAIN1110
  175 CONTINUE                                                               MAIN1115
C                                                                            MAIN1120
C                                                                            MAIN1125
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      CALL UPPER (ALAT)                                                  MAIN1130
C                                                                        MAIN1135
CC    EXPAND 56 LEVEL TO 100 LEVEL ATMOSPHERE                            MAIN1140
CCC                                                                      MAIN1145
CCC                                                                      MAIN1150
C                                                                        MAIN1155
      DO 180 I=1,100                                                     MAIN1160
      AB = FLOAT(I)                                                      MAIN1165
      AAB = (1.+(.26087836*(AB-1.0)))**3.50                              MAIN1170
      VTPR(1,I) = AAB*.01                                                MAIN1175
      VTPR(2,I) = 99.9                                                   MAIN1180
  180 CONTINUE                                                           MAIN1185
C                                                                        MAIN1190
      VTPR(1,100) = 1000.000                                             MAIN1200
C                                                                        MAIN1205
C                                                                        MAIN1210
      DO 185 I=34,56                                                     MAIN1215
      IF (FG(2,I).LT.99.8) GO TO 185                                     MAIN1220
      CALL LEVELL (FG(1,I),TT)                                           MAIN1225
      FG(2,I) = TT                                                       MAIN1230
  185 CONTINUE                                                           MAIN1235
C                                                                        MAIN1240
C                                                                        MAIN1255
      DO 190 I=1,100                                                     MAIN1260
      CALL LEVELL (VTPR(1,I),TT)                                         MAIN1265
      VTPR(2,I) = TT                                                     MAIN1270
  190 CONTINUE                                                           MAIN1275
C                                                                        MAIN1280
CC                                                                       MAIN1290
CCC   CONVERT TEMPERATURES TO KELVIN                                     MAIN1295
CCC                                                                      MAIN1300
C                                                                        MAIN1310
      DO 195 I=1,100                                                     MAIN1315
      VTPR(2,I) = VTPR(2,I)+273.16                                       MAIN1320
  195 CONTINUE                                                           MAIN1325
C                                                                        MAIN1330
CC                                                                       MAIN1340
CCC   SET A COUNTER - IFLAG - TO COUNT THE NJMBER OF ITERATIONS USED     MAIN1345
CC    TO CONVERGE                                                        MAIN1350
C                                                                        MAIN1355
      IFLAG = 0                                                          MAIN1360
  200 VTPR(2,100) = TSFC                                                 MAIN1365
C                                                                        MAIN1370
CCC   CALCULATE THE TRANSMITTANCE DUE TO CO2                             MAIN1375
C                                                                        MAIN1380
      CALL RDTEMP (PATH)                                                 MAIN1385
C                                                                        MAIN1390
C     IF THE ZENITH ANGLE IS GREATER THAN ZERO THAN THE VALUES OF TAU    MAIN1395
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C      MUST BE CORRECTED.                                                MAIN1400
C                                                                        MAIN1405
       CALL MARTAU (PATH)                                                MAIN1410
       IF (IFLAG.GE.1) GO TO 230                                         MAIN1415
C                                                                        MAIN1420
CC     DETERMINE THE WATER VAPOR CONTENT OF THE ATMOSPHERE               MAIN1425
C                                                                        MAIN1430
       KK = 1                                                            MAIN1435
C                                                                        MAIN1440
C                                                                        MAIN1445
       DO 205 I=63,100                                                   MAIN1450
       IF (I.NE.LEVEL(KK)) GO TO 205                                     MAIN1455
       SAT(KK) = GOFF(VTPR(2,I),VTPR(1,I))                               MAIN1460
       KK = KK+1                                                         MAIN1465
   205 CONTINUE                                                          MAIN1470
C                                                                        MAIN1475
CCCC                                                                     MAIN1480
CCCCC                                                                    MAIN1485
CCCCC  FORM W FIRST GUESS =WBAR+CREG*(SAT-TBAR)                          MAIN1490
CCCCC                                                                    MAIN1495
CCC                                                                      MAIN1500
                                                                         MAIN1505
       DO 215 M=1,40                                                     MAIN1510
       W(M) = WBAR(M)                                                    MAIN1515
CC                                                                       MAIN1520
                                                                         MAIN1525
       DO 210 L=1,11                                                     MAIN1530
       W(M) = W(M)+CREG(M,L)*(SAT(L)-TBAR(L))                            MAIN1535
   210 CONTINUE                                                          MAIN1540
C                                                                        MAIN1545
CC                                                                       MAIN1550
   215 CONTINUE                                                          MAIN1555
CC                                                                       MAIN1560
                                                                         MAIN1575
       DO 220 M=61,100                                                   MAIN1580
       W(M) = W(M-61+1)                                                  MAIN1585
       IF (W(M).LT.0.00) W(M)=0.00                                       MAIN1590
   220 CONTINUE                                                          MAIN1595
C                                                                        MAIN1600
CCCC                                                                     MAIN1605
                                                                         MAIN1610
CCC                                                                      MAIN1615
       DO 225 M=1,61                                                     MAIN1620
       W(M) = W(61)*(VTPR(1,M)/VTPR(2,61))**3                            MAIN1625
       IF (W(M).LT.0.00) W(M)=0.00                                       MAIN1630
   225 CONTINUE                                                          MAIN1635
C                                                                        MAIN1640
C                                                                        MAIN1645
```

```
C      CALCULATE THE TRANSMITTANCE DUE TO WATER VAPOR                    MAIN1650
C                                                                        MAIN1655
  230 CALL TRANW (TOTWV,1,8)                                             MAIN1660
C                                                                        MAIN1665
C                                                                        MAIN1670
      DO 240 I=1,100                                                     MAIN1675
C                                                                        MAIN1680
C                                                                        MAIN1685
      DO 235 J=1,6                                                       MAIN1690
C                                                                        MAIN1695
CC    TOTAL TRANSMITTANCE IS THE PRODUCT OF CO2*WATER*OZONE              MAIN1700
C                                                                        MAIN1705
      TAUW(I,J) = TAU(I,J)*TAUW(I,J)*OZTAU(I,J)**PATH                    MAIN1710
  235 CONTINUE                                                           MAIN1715
C                                                                        MAIN1720
C                                                                        MAIN1725
  240 CONTINUE                                                           MAIN1730
CC                                                                       MAIN1735
C                                                                        MAIN1740
      IF (IFLAG.GT.1) GO TO 265                                          MAIN1745
      VTPR(2,100) = TSFC                                                 MAIN1750
C                                                                        MAIN1755
CCC   COMPUTE PLANCK VALUES AT 100 LEVELS                                MAIN1760
C                                                                        MAIN1765
C                                                                        MAIN1770
C                                                                        MAIN1775
      DO 250 I=1,6                                                       MAIN1780
C                                                                        MAIN1785
C                                                                        MAIN1790
      DO 245 J=1,100                                                     MAIN1795
      BB(J,I) = (C1*CHAN(I)**3)/(EXP(C2*CHAN(I)/VTPR(2,J))-1.)           MAIN1800
  245 CONTINUE                                                           MAIN1805
C                                                                        MAIN1810
CC                                                                       MAIN1815
  250 CONTINUE                                                           MAIN1820
C                                                                        MAIN1825
C                                                                        MAIN1830
C                                                                        MAIN1835
CCC   COMPUTE 33 LEVEL PLANCK FUNCTION BY USING A 4TH ORDER LAGRANGIAN   MAIN1840
C                                                                        MAIN1845
C                                                                        MAIN1850
C                                                                        MAIN1855
      DO 260 I=1,6                                                       MAIN1860
      K = 1                                                              MAIN1865
C                                                                        MAIN1870
C                                                                        MAIN1875
      DO 255 J=4,100,3                                                   MAIN1880
      X = ((J-1)+(J-2))/2.                                               MAIN1885
```

```
      B(K,I) = BB(J,I)*(X-(J-1))*(X-(J-2))*(X-(J-3))/((J-(J-1))*(J-(J-2)MAIN1890
     1)*(J-(J-3)))+BB(J-1,I)*(X-J)*(X-(J-2))*(X-(J-3))/(((J-1)-J)*((J-1)MAIN1895
     2-(J-2))*((J-1)-(J-3)))+BB(J-2,I)*(X-J)*(X-(J-1))*(X-(J-3))/(((J-2)MAIN1900
     3-J)*((J-2)-(J-1))*((J-2)-(J-3)))+BB(J-3,I)*(X-J)*(X-(J-1))*(X-(J-2MAIN1905
     4))/(((J-3)-J)*((J-3)-(J-1))*((J-3)-(J-2)))                        MAIN1910
      K = K+1                                                           MAIN1915
  255 CONTINUE                                                          MAIN1920
C                                                                       MAIN1925
C                                                                       MAIN1930
  260 CONTINUE                                                          MAIN1935
C                                                                       MAIN1940
CCCCC                                                                   MAIN1945
CCCCC                                                                   MAIN1950
CCCCC     COMPUTE DELTA TAUW FOR 100 LEVELS                             MAIN1955
CCCCC                                                                   MAIN1960
CCCCC                                                                   MAIN1965
C                                                                       MAIN1970
  265 DO 275 I=1,6                                                      MAIN1975
      DDTAUW(1,I) = ABS(TAUW(1,I)-TAUW(2,I))*2                          MAIN1980
      DDTAUW(100,I) = ABS(TAUW(99,I)-TAUW(100,I))*2                     MAIN1985
C                                                                       MAIN1990
C                                                                       MAIN1995
      DO 270 J=2,99                                                     MAIN2000
      DDTAUW(J,I) = ABS(TAUW(J+1,I)-TAUW(J-1,I))                        MAIN2005
  270 CONTINUE                                                          MAIN2010
C                                                                       MAIN2015
C                                                                       MAIN2020
  275 CONTINUE                                                          MAIN2025
C                                                                       MAIN2030
CCCCC                                                                   MAIN2035
CCCCC                                                                   MAIN2040
CCCCC     COMPUTE DELTA TAUW FOR THE 33 LEVELS                          MAIN2045
CCCCC                                                                   MAIN2050
CCCCC                                                                   MAIN2055
C                                                                       MAIN2060
      DO 285 I=1,6                                                      MAIN2065
      K = 1                                                             MAIN2070
C                                                                       MAIN2075
C                                                                       MAIN2080
      DO 280 J=4,100,3                                                  MAIN2085
      DTAUW(K,I) = TAUW(J-3,I)-TAUW(J,I)                                MAIN2090
      K = K+1                                                           MAIN2095
  280 CONTINUE                                                          MAIN2100
C                                                                       MAIN2105
C                                                                       MAIN2110
  285 CONTINUE                                                          MAIN2115
C                                                                       MAIN2120
C                                                                       MAIN2125
```

```
C                                                                       MAIN2130
CC     COMPUTE MEAN LAYER PLANCK VALUES                                 MAIN2135
CCC                                                                     MAIN2140
CCC                                                                     MAIN2145
C                                                                       MAIN2150
      DO 295 I=1,6                                                      MAIN2155
      K = 1                                                             MAIN2160
C                                                                       MAIN2165
C                                                                       MAIN2170
      DO 290 J=4,100,3                                                  MAIN2175
      BMEAN(K,I) = (BB(J,I)+4.*B(K,I)+BB(J-3,I))/6.                     MAIN2180
      K = K+1                                                           MAIN2185
  290 CONTINUE                                                          MAIN2190
C                                                                       MAIN2195
CC                                                                      MAIN2200
  295 CONTINUE                                                          MAIN2205
C                                                                       MAIN2210
      IFLAG = IFLAG+1                                                   MAIN2215
CC                                                                      MAIN2220
CCC                                                                     MAIN2225
CCCC   COMPUTE FIRST GUESS RADIANCE                                     MAIN2230
CCC                                                                     MAIN2235
CC                                                                      MAIN2240
      DO 315 I=1,6                                                      MAIN2245
      IF (TAUW(100,I).LT.1.E-07) GO TO 300                              MAIN2250
      RADSFC = BB(100,I)*TAUW(100,I)                                    MAIN2255
      GO TO 305                                                         MAIN2260
  300 RADSFC = 0.0                                                      MAIN2265
  305 RADATM = 0.0                                                      MAIN2270
C                                                                       MAIN2275
CC                                                                      MAIN2280
      DO 310 K=1,33                                                     MAIN2285
      IF (DTAUW(K,I).LT.1.E-07) GO TO 310                               MAIN2290
      RAD = BMEAN(K,I)*DTAUW(K,I)                                       MAIN2295
      RADATM = RADATM+RAD                                               MAIN2300
  310 CONTINUE                                                          MAIN2305
C                                                                       MAIN2310
CC                                                                      MAIN2315
      RADTOT(I) = RADATM+RADSFC                                         MAIN2320
  315 CONTINUE                                                          MAIN2325
C                                                                       MAIN2330
CC                                                                      MAIN2335
      KOUNT = 0                                                         MAIN2340
C                                                                       MAIN2345
CC                                                                      MAIN2350
      DO 330 I=1,6                                                      MAIN2355
      RESID = RADOBS(I)-RADTOT(I)                                       MAIN2360
                                                                        MAIN2365
```

```
      EPS = ABS(RESID/RADOBS(I))                                        MAIN2370
C                                                                       MAIN2375
CC    TEST FOR CONVERGENCE OF THE COMPUTED AND OBSERVED RADIANCES       MAIN2380
C                                                                       MAIN2385
      IF (EPS.LT.1.E-04) GO TO 330                                      MAIN2390
      KOUNT = KOUNT+1                                                   MAIN2395
C                                                                       MAIN2400
C                                                                       MAIN2405
      DO 320 K=1,33                                                     MAIN2410
      B(K,I) = B(K,I)+RESID                                             MAIN2415
  320 CONTINUE                                                          MAIN2420
C                                                                       MAIN2425
CC                                                                      MAIN2430
CC    COMPUTE NEW PLANCKS FOR NEXT ITERATION                            MAIN2435
CCC                                                                     MAIN2440
CC                                                                      MAIN2445
C                                                                       MAIN2450
      DO 325 J=1,100                                                    MAIN2455
      BB(J,I) = BB(J,I)+RESID                                           MAIN2460
  325 CONTINUE                                                          MAIN2465
C                                                                       MAIN2470
C                                                                       MAIN2475
  330 CONTINUE                                                          MAIN2480
C                                                                       MAIN2485
C                                                                       MAIN2490
      DO 340 J=1,100                                                    MAIN2495
      SUMDT = 0.0                                                       MAIN2500
      SUMBDT = 0.0                                                      MAIN2505
C                                                                       MAIN2510
C                                                                       MAIN2515
      DO 335 I=1,6                                                      MAIN2520
      SUMBDT = SUMBDT+(BB(J,I)*DDTAUW(J,I))                             MAIN2525
      SUMDT = SUMDT+DDTAUW(J,I)                                         MAIN2530
  335 CONTINUE                                                          MAIN2535
C                                                                       MAIN2540
CC                                                                      MAIN2545
      BREF = SUMBDT/SUMDT                                               MAIN2550
      VTPR(2,J) = (C2*710.0)/ALOG((C1*710.0**3+BREF)/BREF)              MAIN2555
  340 CONTINUE                                                          MAIN2560
C                                                                       MAIN2565
C                                                                       MAIN2570
      IF (KOUNT.GT.0) GO TO 200                                         MAIN2575
      WRITE (6,505) IFLAG                                               MAIN2580
C                                                                       MAIN2585
CC    REDUCE THE 100 LEVEL TEMPERATURE PROFILE TO 15 LEVELS WITH A      MAIN2590
CC    FOURTH ORDER LAGRANGIAN                                           MAIN2595
CC                                                                      MAIN2600
C                                                                       MAIN2605
```

```
      DO 355 K=2,15                                                     MAIN2610
      III = 0                                                           MAIN2615
C                                                                       MAIN2620
C                                                                       MAIN2625
      DO 350 J=24,96                                                    MAIN2630
      IF (REPORT(1,K).LE.VTPR(1,J)) GO TO 345                           MAIN2635
      GO TO 350                                                         MAIN2640
  345 IF (III.GE.1) GO TO 350                                           MAIN2645
      Y = VTPR(1,J)-REPORT(1,K)                                         MAIN2650
      Z = VTPR(1,J)-VTPR(1,J-1)                                         MAIN2655
      X = FLOAT(J)-(Y/Z)                                                MAIN2660
      T(K) = VTPR(2,J-2)*(X-(J-1))*(X-J)*(X-(J+1))/(((J-2)-(J-1))*((J-2)MAIN2665
     1-J)*((J-2)-(J+1)))+VTPR(2,J-1)*(X-(J-2))*(X-J)*(X-(J+1))/(((J-1)-(MAIN2670
     2J-2))*((J-1)-J)*((J-1)-(J+1)))+VTPR(2,J)*(X-(J-2))*(X-(J-1))*(X-(JMAIN2675
     3+1))/((J-(J-2))*(J-(J-1))*(J-(J+1)))+VTPR(2,J+1)*(X-(J-2))*(X-(J-1MAIN2680
     4))*(X-J)/(((J+1)-(J-2))*((J+1)-(J-1))*((J+1)-J))                  MAIN2685
      III = 1                                                           MAIN2690
  350 CONTINUE                                                          MAIN2695
C                                                                       MAIN2700
C                                                                       MAIN2705
  355 CONTINUE                                                          MAIN2710
C                                                                       MAIN2715
C                                                                       MAIN2720
      T(1) = VTPR(2,100)                                                MAIN2725
      WRITE (6,515)                                                     MAIN2730
C                                                                       MAIN2735
C     SET COUNTER I FOR LATITUDE BAND                                   MAIN2740
C                                                                       MAIN2745
      IF (ALAT.GT.60.0) I=4                                             MAIN2750
      IF (ALAT.LE.60.0) I=3                                             MAIN2755
      IF (ALAT.LE.40.0) I=2                                             MAIN2760
      IF (ALAT.LE.20.0) I=1                                             MAIN2765
C                                                                       MAIN2770
      DO 360 K=1,15                                                     MAIN2775
      IF (AT(K).GT.99.8) GO TO 360                                      MAIN2780
      ERROR(I,K,LOOP) = T(K)-(AT(K)+273.16)                             MAIN2785
      VERROR(I,K,LOOP) = VT(K)-AT(K)                                    MAIN2790
      T(K)=T(K)-273.16                                                  MAIN2793
      WRITE (6,510) K,REPORT(1,K),T(K),AT(K),ERROR(I,K,LOOP),VT(K),VERROMAIN2795
     1R(I,K,LOOP)                                                       MAIN2800
  360 CONTINUE                                                          MAIN2805
C                                                                       MAIN2810
  365 CONTINUE                                                          MAIN2815
C                                                                       MAIN2820
  370 CONTINUE                                                          MAIN2825
      LLOOP = LOOP-1                                                    MAIN2830
C                                                                       MAIN2835
      DO 390 I=1,4                                                      MAIN2840
```

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C                                                                       MAIN2845
      DO 385 K=1,15                                                     MAIN2850
      N = 0                                                             MAIN2855
C                                                                       MAIN2860
      DO 375 KLOOP=1,LLOOP                                              MAIN2865
      IF (ERROR(I,K,KLOOP).EQ.0.0) GO TO 375                            MAIN2870
      N = N+1                                                           MAIN2875
      TERROR(I,N) = ERROR(I,K,KLOOP)                                    MAIN2880
      TVROR(I,N) = VERROR(I,K,KLOOP)                                    MAIN2885
  375 CONTINUE                                                          MAIN2890
C                                                                       MAIN2895
C                                                                       MAIN2900
      DO 380 II=1,N                                                     MAIN2905
      TROR(II) = TERROR(I,II)                                           MAIN2910
      TVOR(II) = TVROR(I,II)                                            MAIN2915
  380 CONTINUE                                                          MAIN2920
C                                                                       MAIN2925
C                                                                       MAIN2930
C     DRAW HISTOGRAMS OF THE ERRORS                                     MAIN2935
C                                                                       MAIN2940
      CALL HISTG (TROR,N,NBAR)                                          MAIN2945
      WRITE (6,415) REPORT(1,K)                                         MAIN2950
      CALL HISTG (TVOR,N,NBAR)                                          MAIN2955
      WRITE (6,410) REPORT(1,K),I                                       MAIN2960
  385 CONTINUE                                                          MAIN2965
C                                                                       MAIN2970
  390 CONTINUE                                                          MAIN2975
C                                                                       MAIN2980
      STOP                                                              MAIN2985
C                                                                       MAIN2990
C                                                                       MAIN2995
  395 FORMAT (10F7.6)                                                   MAIN3000
  400 FORMAT (F10.3)                                                    MAIN3005
  405 FORMAT ('0',////)                                                 MAIN3010
  410 FORMAT ('0','*****  HISTOGRAM FOR PRESSURE LEVEL ',F6.0,2X,'AND LAMAIN3015
     1TITUDE BAND',I5,2X,'AND USING NESS VTPR *****')                   MAIN3020
  415 FORMAT ('0',F6.0,'MB  HISTOGRAM FOR GLOBALLY AVERAGED ERRORS')    MAIN3025
  420 FORMAT ('0','STATION NUMBER    ',I4)                              MAIN3035
  425 FORMAT (15F4.0)                                                   MAIN3040
  430 FORMAT (15F5.1)                                                   MAIN3045
  435 FORMAT (14F5.1)                                                   MAIN3050
  440 FORMAT (9F8.3)                                                    MAIN3055
  445 FORMAT (10F8.7)                                                   MAIN3060
  450 FORMAT (8F7.3)                                                    MAIN3065
  455 FORMAT (1P6E13.6)                                                 MAIN3070
  460 FORMAT (6(F7.4,3X))                                               MAIN3075
  465 FORMAT (F8.5)                                                     MAIN3080
  470 FORMAT (7E11.4)                                                   MAIN3085
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475 FORMAT (11I3)                                                              MAIN3090
480 FORMAT (8E10.4)                                                            MAIN3095
485 FORMAT (7F8.5)                                                             MAIN3100
490 FORMAT (9F5.1)                                                             MAIN3105
495 FORMAT (9F9.5)                                                             MAIN3110
500 FORMAT (' ','ZENITH ANGLE = ',F4.1)                                        MAIN3115
505 FORMAT ('0','THE TEMPERATURE PROFILE CONVERGED AFTER',I4,'  ITERATMAIN3120
   1IONS')                                                                     MAIN3125
510 FORMAT (' ',I4,2X,6(F10.3,2X))                                             MAIN3130
515 FORMAT ('0',T10,'PRESSURE',T23,'TEMP.',T35,'SOUNDING',T48,'ERROR',MAIN3135
   1T60,'NESS',T72,'NESS-ERROR',/)                                             MAIN3140
    END                                                                        MAIN3145
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      SUBROUTINE UPPER (ALAT)                                                  UPPR   5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCUPPR  10
C                                                                              UPPR  15
C     UPPER CREATES TEMPERATURES FOR A 56 LEVEL ATMOSPHERE FOR THE TIME        UPPR  20
C     YEAR AND LATITUDE OF THE SOUNDING.                                       UPPR  25
C                                                                              UPPR  30
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCUPPR  35
      COMMON/FIRST/STATM(10,56),FG(2,56)                                       UPPR  40
      DIMENSION TEMP(56),TN(56),TS(56)                                         UPPR  45
      C = 0.0                                                                  UPPR  50
      DO 105 I=1,4                                                             UPPR  60
      K = I                                                                    UPPR  65
      C = C+15.                                                                UPPR  70
      AA = C+15.                                                               UPPR  75
      IF (ALAT.GT.C.AND.ALAT.LE.AA) GO TO 110                                  UPPR  80
  105 CONTINUE                                                                 UPPR  85
      RETURN                                                                   UPPR  95
  110 KS = (2*K)-1                                                             UPPR 100
      KN = KS+2                                                                UPPR 105
      KS1 = KS+1                                                               UPPR 110
      KN1 = KN+1                                                               UPPR 115
      DO 115 I=1,56                                                            UPPR 125
      TN(I) = (.6666667*STATM(KN1,I))+(.3333333*STATM(KN,I))                   UPPR 130
      TS(I) = (.6666667*STATM(KS1,I))+(.3333333*STATM(KS,I))                   UPPR 135
  115 CONTINUE                                                                 UPPR 140
C                                                                              UPPR 145
      AS = FLOAT(K)*15.                                                        UPPR 150
      AN = AS+15.                                                              UPPR 155
      BS = (AN-ALAT)/15.                                                       UPPR 160
      BN = (ALAT-AS)/15.                                                       UPPR 165
C     AN=NORTH LAT.,AS=SOUTH LAT.,BN=NORTH WT.,BS=SOUTH WT.                    UPPR 170
      DO 120 I=1,56                                                            UPPR 180
      TEMP(I) = (BS*TS(I))+(BN*TN(I))                                          UPPR 185
  120 CONTINUE                                                                 UPPR 190
C                                                                              UPPR 195
      DIFF = FG(2,34)-(TEMP(34)-273.16)                                        UPPR 200
C     STANDARD STMOSPHERE TEMPERATURE ADJUSTMENT AT 10 MBL                     UPPR 205
      DO 125 I=1,33                                                            UPPR 215
      FG(2,I) = TEMP(I)+DIFF-273.16                                            UPPR 220
  125 CONTINUE                                                                 UPPR 225
C                                                                              UPPR 230
      WRITE (6,130) ALAT,DIFF                                                  UPPR 235
      RETURN                                                                   UPPR 240
  130 FORMAT (' ','STATION LATITUDE = ',F6.2,/, ' STANDARD ATMOSPHERE          UPPR 250
     1TEMPERATURE ADJUSTMENT = ',F7.2)                                         UPPR 255
      END                                                                      UPPR 260
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      SUBROUTINE LEVELL (P,T)                                                    LEVL    5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCLEVL   10
C                                                                                LEVL   15
C     LEVELL ADJUSTS TEMPERATURES FOR A 100 LEVEL ATMOSPHERE                     LEVL   20
C                                                                                LEVL   25
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCLEVL   30
      COMMON/FIRST/STATM(10,56),FG(2,56)                                         LEVL   35
      T = -99.9                                                                  LEVL   40
C                                                                                LEVL   45
      DO 105 I=1,56                                                              LEVL   50
      K = I                                                                      LEVL   55
      IF (FG(1,I).EQ.P.AND.FG(2,I).LT.99.8) GO TO 110                            LEVL   60
      IF (FG(1,I).GE.P) GO TO 115                                                LEVL   65
  105 CONTINUE                                                                   LEVL   70
C                                                                                LEVL   75
      RETURN                                                                     LEVL   80
  110 T = FG(2,K)                                                                LEVL   85
      RETURN                                                                     LEVL   90
  115 KK = K-1                                                                   LEVL   95
      IF (KK.EQ.0) RETURN                                                        LEVL  100
      IF (FG(2,KK).GT.99.8) KK=KK-1                                              LEVL  105
      IF (P.EQ.FG(1,K)) K=K+1                                                    LEVL  110
      IF (FG(2,K).GT.99.8) K=K+1                                                 LEVL  115
      IF (FG(2,K).GT.99.8) K=K+1                                                 LEVL  120
      IF (K.GT.56) RETURN                                                        LEVL  125
      DIFF = (FG(2,KK)-FG(2,K))/(FG(1,K)-FG(1,KK))                               LEVL  130
      PDIFF = FG(1,K)-P                                                          LEVL  135
      T = FG(2,K)+(DIFF*PDIFF)                                                   LEVL  140
      RETURN                                                                     LEVL  145
      END                                                                        LEVL  150
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      SUBROUTINE RDTEMP (PATH)                                          RDTP    5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCRDTP   10
C                                                                       RDTP   15
C     READTEMP RETURNS VALUES OF TRANSMISIVITY AFTER ADJUSTMENT FOR     RDTP   20
C     THE CO2 CONTENT OF THE ATMOSPHERE                                 RDTP   25
C                                                                       RDTP   30
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCRDTP   35
      COMMON/WORK/VTPR(2,100),A1(100,6),A2(100,6),A3(100,6),TAU(100,6)  RDTP   40
      COMMON/SCND/TSTD(100),A(6)                                        RDTP   45
      DIMENSION TAUT(6),D0(6),D1(6),D3(6)                               RDTP   50
C                                                                       RDTP   55
      TD = VTPR(2,1)-TSTD(1)                                            RDTP   60
      TDS = TD**2                                                       RDTP   65
C                                                                       RDTP   70
      DO 105 J=1,6                                                      RDTP   75
      TAU(1,J) = A1(1,J)+A2(1,J)*TD+A3(1,J)*TDS                         RDTP   80
      TAUT(J) = TAU(1,J)                                                RDTP   85
      D0(J) = A1(1,J)                                                   RDTP   90
      D1(J) = A2(1,J)*TD                                                RDTP   95
      D3(J) = (A2(1,J)*A2(2,J)/A1(2,J)+A3(1,J))*TDS                     RDTP  100
  105 CONTINUE                                                          RDTP  105
C                                                                       RDTP  110
C                                                                       RDTP  115
      DO 125 I=2,100                                                    RDTP  120
      TDM1 = TD                                                         RDTP  125
      TD = 0.5*(VTPR(2,I)+VTPR(2,I-1)-TSTD(I)-TSTD(I-1))                RDTP  130
      R = TD/TDM1                                                       RDTP  135
      RS = R**2                                                         RDTP  140
C                                                                       RDTP  145
      DO 120 J=1,6                                                      RDTP  150
      D1(J) = D1(J)*R                                                   RDTP  155
      D3(J) = D3(J)*RS                                                  RDTP  160
      IF (TAUT(J).LT..01) GO TO 110                                     RDTP  165
      COR = (D0(J)+D1(J)+D3(J)-TAUT(J))*A(J)/TAUT(J)                    RDTP  170
      GO TO 115                                                         RDTP  175
  110 COR = (D0(J)+D1(J)+D3(J)-TAUT(J))*A(J)                            RDTP  180
  115 C4 = A2(I,J)*TD                                                   RDTP  185
      C5 = A3(I,J)*TD*TD                                                RDTP  190
      C6 = A1(I,J)                                                      RDTP  195
      DCOEF = C6+C4+C5                                                  RDTP  200
      TAU(I,J) = TAU(I-1,J)*(DCOEF+COR)                                 RDTP  205
      TAUT(J) = TAUT(J)*DCOEF                                           RDTP  210
      D3(J) = D3(J)*C6+D0(J)*C5+D1(J)*C4                                RDTP  215
      D1(J) = D1(J)*C6+D0(J)*C4                                         RDTP  220
      D0(J) = D0(J)*C6                                                  RDTP  225
  120 CONTINUE                                                          RDTP  230
C                                                                       RDTP  235
  125 CONTINUE                                                          RDTP  240
```

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C                                                                       RDTP  245
C                                                                       RDTP  250
      DO 130  I=1,6                                                     RDTP  255
C                                                                       RDTP  260
      DO 130 K=1,100                                                    RDTP  265
      TAU(K,I) = CHOP(TAU(K,I),0.0,1.0)                                 RDTP  270
  130 CONTINUE                                                          RDTP  275
C                                                                       RDTP  280
      RETURN                                                            RDTP  285
      END                                                               RDTP  290
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      SUBROUTINE MARTAU (PATH)                                                  MATU   5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCMATU  10
C                                                                               MATU  15
C     MARTAU ADJUSTS THE VALUES OF TAU FOR THE ZENITH ANGLE                     MATU  20
C                                                                               MATU  25
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCMATU  30
      COMMON/WORK/VTPR(2,100),A1(100,6),A2(100,6),A3(100,6),TAU(100,6)          MATU  35
      COMMON/SCND/TSTD(100),A(6)                                                MATU  40
      COMMON/THRD/D1(6),D4(6),D5(6),D10(6),D12(6)                               MATU  45
      REAL*8 FN,TRA,TRAN                                                        MATU  50
C                                                                               MATU  55
      DO 115 K=1,100                                                            MATU  60
      IF (K.EQ.1) TT1 = .01*TSTD(1)                                             MATU  65
      IF (K.EQ.1) GO TO 105                                                     MATU  70
      DELP = VTPR(1,K)-VTPR(1,K-1)                                              MATU  75
      TT1 = TT1+.5*(TSTD(K)+TSTD(K-1))*DELP                                     MATU  80
  105 TLN = ALOG(TT1/(VTPR(1,K)*273.))                                          MATU  85
      PLN = ALOG(VTPR(1,K)/2000.)                                               MATU  90
C                                                                               MATU  95
      DO 110 I=1,6                                                              MATU 100
      FN = D1(I)+PLN*D4(I)+TLN*D5(I)+TLN*TLN*D10(I)+PLN*TLN*D12(I)              MATU 105
      FN = .1*FN                                                                MATU 110
      FN = PATH**FN                                                             MATU 115
      TAU(K,I) = TAU(K,I)**FN                                                   MATU 120
      TAU(K,I) = CHOP(TAU(K,I),0.0,1.0)                                         MATU 125
  110 CONTINUE                                                                  MATU 130
C                                                                               MATU 135
  115 CONTINUE                                                                  MATU 140
C                                                                               MATU 145
      RETURN                                                                    MATU 150
      END                                                                       MATU 155
```

```
      FUNCTION GOFF( T,PP)                                                  GOFF   5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCGOFF  10
C                                                                           GOFF  12
C     GOFF RETURNS SATURATED MIXING RATIO GIVEN TEMP AND PRESS              GOFF  15
C                                                                           GOFF  20
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCGOFF  25
      TS = 373.16                                                           GOFF  30
      AA = -7.90298*(TS/T-1.)                                               GOFF  35
      BB = 5.02808*ALOG10(TS/T)                                             GOFF  40
      C = 11.344*(1.-(T/TS))                                                GOFF  45
      CC = (-1.3816E-07)*(10**C-1)                                          GOFF  50
      D = -3.49149*(TS/T-1.)                                                GOFF  55
      DD = (8.1328E-03)*(10**D-1)                                           GOFF  60
      ESUBS = 1013.246*10**(AA+BB+CC+DD)                                    GOFF  65
C                                                                           GOFF  70
CC    FROM SAT VAPOR PRESSURE GET SAT MIXING RATIO                          GOFF  75
C                                                                           GOFF  80
      GOFF = 621.98*ESUBS/(PP-ESUBS)                                        GOFF  85
      RETURN                                                                GOFF  90
      END                                                                   GOFF  95
```

```
      SUBROUTINE TRANW (TOTWV,NA,NZ)                                    TRNW    5
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCTRNW   10
C                                                                       TRNW   15
C     TRANW COMPUTES TRANSMISIVITY FOR WATER VAPOR                      TRNW   20
C                                                                       TRNW   25
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCTRNW   30
      COMMON/WORK/VTPR(2,100),A1(100,6),A2(100,6),A3(100,6),TAU(100,6)  TRNW   35
      COMMON/FOUR/DIM(100),TAUW(100,8),CW(8,14),U(100),AA(14),PATH,NP,  TRNW   40
     1W(100)                                                            TRNW   45
      DIMENSION BIGNEL(8)                                               TRNW   50
      DATA BIGNEL/4.90E-08,4.73E-08,4.33E-08,4.07E-08,3.75E-08,3.38E-08,TRNW   55
     12.04E-08,9.63E-08/                                                TRNW   60
      CGRAV = 0.5/980.665                                               TRNW   65
      U(1) = 0.0                                                        TRNW   70
      DIM(1) = 0.0                                                      TRNW   75
      SAVE = 0.0                                                        TRNW   80
      TNOT = 303.16                                                     TRNW   85
      DO 105 K=2,NP                                                     TRNW   95
      DELP = VTPR(1,K)-VTPR(1,K-1)                                      TRNW  100
      U(K) = U(K-1)+CGRAV*(W(K-1)+W(K))*DELP                            TRNW  105
C                                                                       TRNW  110
C     COMPUTE THE ARGUMENT OF DIMER CONTRIBUTION                        TRNW  115
C                                                                       TRNW  120
      TOT = TNOT/VTPR(2,K)                                              TRNW  125
      PW2T5 = VTPR(1,K)*W(K)*W(K)*(TOT**5)                              TRNW  130
      DIM(K) = DIM(K-1)+(SAVE+PW2T5)*DELP/2.0                           TRNW  135
      SAVE = PW2T5                                                      TRNW  140
  105 CONTINUE                                                          TRNW  145
C                                                                       TRNW  150
C                                                                       TRNW  155
      DO 110 K=1,NP                                                     TRNW  160
      U(K) = PATH*U(K)                                                  TRNW  165
      DIM(K) = DIM(K)*PATH                                              TRNW  170
C                                                                       TRNW  175
      DO 110 I=NA,NZ                                                    TRNW  180
      TAUW(K,I) = 1.0                                                   TRNW  185
  110 CONTINUE                                                          TRNW  190
C                                                                       TRNW  195
      TOTWV = U(NP)                                                     TRNW  200
      DO 135 I=NA,NZ                                                    TRNW  210
      IFLAG = 0                                                         TRNW  215
C                                                                       TRNW  220
      DO 130 K=2,NP                                                     TRNW  225
      IF (U(K).LE.1.0E-06) GO TO 130                                    TRNW  230
      PP = (VTPR(1,K)+VTPR(1,K-1))/2000.                                TRNW  235
      TT = (VTPR(2,K)+VTPR(2,K-1))/546.                                 TRNW  240
      AA(3) = ALOG(PP)                                                  TRNW  245
      AA(4) = ALOG(TT)                                                  TRNW  250
```

```
      AA(9) = AA(3)*AA(4)                                                    TRNW  255
      AA(12) = AA(4)**2                                                      TRNW  260
      COF3 = CW(I,10)                                                        TRNW  265
      COF2 = CW(I,7)+CW(I,8)*AA(4)+CW(I,14)*AA(3)                            TRNW  270
      COF1 = CW(I,2)+CW(I,5)*AA(3)+CW(I,6)*AA(4)+CW(I,11)*AA(12)+CW(I,13TRNW  275
     1)*AA(9)                                                                TRNW  280
      COF0 = CW(I,1)+CW(I,3)*AA(3)+CW(I,4)*AA(4)+CW(I,9)*AA(9)+CW(I,12)*TRNW  285
     1AA(12)                                                                 TRNW  290
      IFLAG = IFLAG+1                                                        TRNW  295
C                                                                            TRNW  300
CC    FIRST TIME U IS NON-ZERO, COMPUTE TAUW DIRECTLY FROM POLY EXPANSIOTRNW  305
C                                                                            TRNW  310
      IF (IFLAG.NE.1) GO TO 115                                              TRNW  315
      D = U(K)                                                               TRNW  320
      GO TO 125                                                              TRNW  325
C                                                                            TRNW  330
CC    FROM WW(K-1) COMPUTE UPSTART  THEN ADD DELTA U                         TRNW  335
CCC                                                                          TRNW  340
CCC   NEWTONS METHOD TO SOLVE FOR AA(2). 1ST GUESS IS LAST VALUE OF AA       TRNW  345
C                                                                            TRNW  350
  115 A22 = AA(2)**2                                                         TRNW  355
      A23 = AA(2)**3                                                         TRNW  360
      F = COF0+COF1*AA(2)+COF2*A22+COF3*A23                                  TRNW  365
      F = F-WW                                                               TRNW  370
      F1 = COF1+2.0*COF2*AA(2)+3.0*COF3*A22                                  TRNW  375
      IF (F1.EQ.0.0) GO TO 120                                               TRNW  380
      AA(2) = AA(2)-F/F1                                                     TRNW  385
C                                                                            TRNW  390
CC    NOW HAVE AA(2). DERIVE U-START AND ADD DELTA-U                         TRNW  395
C                                                                            TRNW  400
  120 D = EXP(10.*AA(2)-AA(4))+U(K)-U(K-1)                                   TRNW  405
  125 AA(2) = 0.1*(ALOG(D)+AA(4))                                            TRNW  410
      A22 = AA(2)**2                                                         TRNW  415
      A23 = AA(2)**3                                                         TRNW  420
C                                                                            TRNW  425
CC    WW IS LOG(-LOG(TAUW))                                                  TRNW  430
C                                                                            TRNW  435
      WW = COF0+COF1*AA(2)+COF2*A22+COF3*A23                                 TRNW  440
      XARG = DIM(K)*BIGNEL(I)+EXP(WW)                                        TRNW  445
      TRAN = EXP(-XARG)                                                      TRNW  450
      TAUW(K,I) = CHOP(TRAN,0.0,1.0)                                         TRNW  455
  130 CONTINUE                                                               TRNW  460
C                                                                            TRNW  465
  135 CONTINUE                                                               TRNW  470
C                                                                            TRNW  475
      RETURN                                                                 TRNW  480
      END                                                                    TRNW  485
```

```
      FUNCTION CHOP(X,Y,Z)                                          CHOP    5
      IF (X-Y) 105,105,110                                          CHOP   10
  105 CHOP = Y                                                      CHOP   15
      RETURN                                                        CHOP   20
  110 IF (X-Z) 120,115,115                                          CHOP   25
  115 CHOP = Z                                                      CHOP   30
      RETURN                                                        CHOP   35
  120 CHOP = X                                                      CHOP   40
      RETURN                                                        CHOP   45
      END                                                           CHOP   50
```

CARBON DIOXIDE TRANSMITTANCES FOR THE SIX VTPR CHANNELS

LEVEL	CHAN 1	CHAN 2	CHAN 3	CHAN 4	CHAN 5	CHAN 6
1	0.991131	0.999653	0.999886	0.999912	0.999936	0.999993
2	0.988616	0.999418	0.999733	0.999799	0.999842	0.999985
3	0.985314	0.999092	0.999537	0.999575	0.999653	0.999962
4	0.980754	0.998608	0.999259	0.999173	0.999308	0.999909
5	0.975299	0.997973	0.998884	0.998641	0.998848	0.999815
6	0.969083	0.997204	0.998390	0.998053	0.998348	0.999674
7	0.961684	0.996247	0.997750	0.997415	0.997822	0.999486
8	0.952678	0.995045	0.996952	0.996738	0.997281	0.999258
9	0.941640	0.993540	0.995971	0.996022	0.996731	0.998991
10	0.928429	0.991679	0.994789	0.995254	0.996155	0.998697
11	0.913059	0.989418	0.993404	0.994433	0.995537	0.998400
12	0.895530	0.986719	0.991792	0.993556	0.994859	0.998101
13	0.875965	0.983537	0.989937	0.992624	0.994112	0.997802
14	0.854614	0.979809	0.987813	0.991627	0.993282	0.997503
15	0.831837	0.975464	0.985379	0.990533	0.992342	0.997193
16	0.808120	0.970429	0.982596	0.989324	0.991280	0.996866
17	0.783978	0.964630	0.979426	0.987985	0.990083	0.996519
18	0.759806	0.957987	0.975819	0.986496	0.988739	0.996145
19	0.735895	0.950424	0.971736	0.984847	0.987244	0.995739
20	0.712363	0.941861	0.967135	0.983030	0.985595	0.995301
21	0.689153	0.932223	0.961984	0.981041	0.983792	0.994828
22	0.666067	0.921432	0.956255	0.978881	0.981841	0.994319
23	0.642842	0.909414	0.949899	0.976531	0.979731	0.993767
24	0.619215	0.896098	0.942897	0.973993	0.977470	0.993178
25	0.594999	0.881417	0.935216	0.971258	0.975059	0.992548
26	0.570067	0.865308	0.926777	0.968284	0.972473	0.991863
27	0.544428	0.847723	0.917538	0.965057	0.969713	0.991121
28	0.518133	0.828618	0.907477	0.961575	0.966787	0.990321
29	0.491282	0.807966	0.896576	0.957838	0.963705	0.989465
30	0.463997	0.785753	0.884823	0.953848	0.960479	0.988555
31	0.436414	0.761986	0.872210	0.949607	0.957125	0.987592
32	0.408677	0.736687	0.858738	0.945123	0.953658	0.986582
33	0.380939	0.709907	0.844414	0.940408	0.950097	0.985527
34	0.353356	0.681707	0.829254	0.935474	0.946459	0.984435
35	0.326084	0.652176	0.813267	0.930328	0.942757	0.983308
36	0.299286	0.621431	0.796393	0.924929	0.938977	0.982135
37	0.273120	0.589637	0.778590	0.919237	0.935107	0.980904
38	0.247735	0.556957	0.759887	0.913260	0.931157	0.979618
39	0.223274	0.523557	0.740321	0.907008	0.927138	0.978282
40	0.199827	0.489605	0.720067	0.900580	0.923095	0.976925

41	0.177535	0.455338	0.699027	0.893880	0.918984	0.975520
42	0.156501	0.420970	0.677231	0.886900	0.914800	0.974066
43	0.136779	0.386711	0.654787	0.879668	0.910554	0.972570
44	0.118460	0.352818	0.631511	0.872086	0.906201	0.971004
45	0.101568	0.319468	0.607929	0.864268	0.901789	0.969402
46	0.086144	0.286895	0.583764	0.856180	0.897299	0.967754
47	0.072217	0.255350	0.559096	0.847746	0.892698	0.966037
48	0.059791	0.225062	0.533982	0.838940	0.887974	0.964244
49	0.048830	0.196242	0.508515	0.829770	0.883125	0.962375
50	0.039287	0.169099	0.482838	0.820248	0.878152	0.960436
51	0.031120	0.143870	0.456970	0.810294	0.873021	0.958401
52	0.024258	0.120747	0.430848	0.799742	0.867663	0.956221
53	0.018584	0.099830	0.404528	0.788502	0.862036	0.953867
54	0.013970	0.081190	0.378156	0.776550	0.856124	0.951329
55	0.010292	0.064897	0.351884	0.763863	0.849909	0.948596
56	0.007424	0.050927	0.325859	0.750427	0.843377	0.945657
57	0.005227	0.039151	0.300236	0.736235	0.836517	0.942505
58	0.003538	0.029433	0.275213	0.721332	0.829334	0.939146
59	0.002388	0.021629	0.250973	0.705756	0.821833	0.935582
60	0.001541	0.015515	0.227612	0.689479	0.813992	0.931796
61	0.000968	0.010838	0.205211	0.672462	0.805783	0.927765
62	0.000591	0.007353	0.183853	0.654664	0.797179	0.923464
63	0.000341	0.004810	0.163611	0.636031	0.788142	0.918861
64	0.000180	0.003047	0.144515	0.616461	0.778612	0.913897
65	0.000082	0.001886	0.126588	0.595843	0.768520	0.908503
66	0.000020	0.001156	0.109856	0.574072	0.757798	0.902609
67	0.000000	0.000691	0.094406	0.551202	0.746438	0.896197
68	0.0	0.000395	0.080334	0.527442	0.734486	0.889290
69	0.0	0.000221	0.067655	0.502886	0.721936	0.881867
70	0.0	0.000123	0.056346	0.477534	0.708741	0.873871
71	0.0	0.000060	0.046403	0.451509	0.694903	0.865288
72	0.0	0.000019	0.037766	0.425025	0.680453	0.856134
73	0.0	0.000000	0.030335	0.398223	0.665387	0.846389
74	0.0	0.0	0.023984	0.371034	0.649593	0.835938
75	0.0	0.0	0.018661	0.343825	0.633165	0.824852
76	0.0	0.0	0.014292	0.316940	0.616200	0.813206
77	0.0	0.0	0.010759	0.290388	0.598623	0.800919
78	0.0	0.0	0.007967	0.264438	0.580505	0.788043
79	0.0	0.0	0.005844	0.239271	0.561878	0.774598
80	0.0	0.0	0.004220	0.215037	0.542755	0.760583

81	0.0	0.0	0.002995	0.191890	0.523149	0.745995
82	0.0	0.0	0.002071	0.170036	0.503112	0.730874
83	0.0	0.0	0.001380	0.149654	0.482760	0.715302
84	0.0	0.0	0.000885	0.130787	0.462181	0.699323
85	0.0	0.0	0.000548	0.113420	0.441413	0.682954
86	0.0	0.0	0.000334	0.097547	0.420495	0.666182
87	0.0	0.0	0.000208	0.083170	0.399466	0.649015
88	0.0	0.0	0.000132	0.070295	0.378367	0.631455
89	0.0	0.0	0.0	0.058915	0.357233	0.613499
90	0.0	0.0	0.0	0.048942	0.336122	0.595161
91	0.0	0.0	0.0	0.040301	0.315182	0.576550
92	0.0	0.0	0.0	0.032900	0.294559	0.557781
93	0.0	0.0	0.0	0.026612	0.274311	0.538879
94	0.0	0.0	0.0	0.021319	0.254492	0.519862
95	0.0	0.0	0.0	0.016910	0.235156	0.500744
96	0.0	0.0	0.0	0.013286	0.216375	0.481554
97	0.0	0.0	0.0	0.010351	0.198231	0.462330
98	0.0	0.0	0.0	0.008008	0.180793	0.443100
99	0.0	0.0	0.0	0.006171	0.164126	0.423879
100	0.0	0.0	0.0	0.004732	0.148023	0.404273

WATER VAPOR TRANSMITTANCES FOR THE SIX VTPR CHANNELS

LEVEL	CHAN 1	CHAN 2	CHAN 3	CHAN 4	CHAN 5	CHAN 6
1	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
2	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
3	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
4	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
5	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
6	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
7	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
8	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
9	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
10	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
11	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
12	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
13	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
14	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
15	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
16	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
17	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
18	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
19	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
20	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
21	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
22	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
23	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
24	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
25	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
26	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
27	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
28	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
29	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
30	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
31	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
32	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
33	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
34	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
35	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
36	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
37	0.999999	1.000000	1.000000	1.000000	1.000000	1.000000
38	0.999999	1.000000	1.000000	1.000000	1.000000	1.000000
39	0.999998	1.000000	1.000000	1.000000	1.000000	1.000000
40	0.999997	1.000000	1.000000	1.000000	1.000000	1.000000

41	0.999996	1.000000	0.999999	0.999999	1.000000	1.000000
42	0.999993	1.000000	0.999999	0.999999	1.000000	1.000000
43	0.999990	0.999999	0.999998	0.999998	1.000000	1.000000
44	0.999985	0.999999	0.999997	0.999997	1.000000	1.000000
45	0.999978	0.999999	0.999996	0.999995	1.000000	1.000000
46	0.999968	0.999998	0.999993	0.999993	1.000000	0.999999
47	0.999955	0.999997	0.999991	0.999990	0.999999	0.999999
48	0.999938	0.999996	0.999987	0.999985	0.999999	0.999999
49	0.999915	0.999994	0.999981	0.999979	0.999998	0.999998
50	0.999884	0.999991	0.999973	0.999970	0.999997	0.999997
51	0.999845	0.999987	0.999963	0.999959	0.999996	0.999995
52	0.999794	0.999982	0.999949	0.999943	0.999995	0.999994
53	0.999728	0.999975	0.999929	0.999921	0.999992	0.999991
54	0.999645	0.999965	0.999902	0.999891	0.999988	0.999986
55	0.999540	0.999951	0.999865	0.999852	0.999983	0.999980
56	0.999409	0.999933	0.999816	0.999799	0.999976	0.999971
57	0.999246	0.999909	0.999750	0.999730	0.999966	0.999958
58	0.999046	0.999877	0.999663	0.999640	0.999952	0.999940
59	0.998802	0.999835	0.999550	0.999525	0.999934	0.999915
60	0.998508	0.999782	0.999406	0.999380	0.999910	0.999884
61	0.998154	0.999714	0.999221	0.999196	0.999878	0.999841
62	0.997638	0.999609	0.998936	0.998915	0.999827	0.999772
63	0.996922	0.999451	0.998507	0.998501	0.999749	0.999662
64	0.996058	0.999246	0.997946	0.997970	0.999644	0.999511
65	0.995036	0.998985	0.997228	0.997302	0.999507	0.999308
66	0.993836	0.998659	0.996322	0.996477	0.999331	0.999040
67	0.992429	0.998254	0.995187	0.995462	0.999107	0.998691
68	0.990770	0.997752	0.993765	0.994211	0.998823	0.998236
69	0.988810	0.997129	0.991987	0.992674	0.998464	0.997545
70	0.986513	0.996367	0.989793	0.990807	0.998014	0.996891
71	0.983706	0.995397	0.986988	0.988452	0.997429	0.995893
72	0.980191	0.994134	0.983340	0.985424	0.996650	0.994548
73	0.975928	0.992542	0.978758	0.981663	0.995646	0.992799
74	0.970894	0.990595	0.973175	0.977128	0.994392	0.990596
75	0.965046	0.988257	0.966507	0.971763	0.992855	0.987877
76	0.958313	0.985478	0.958637	0.965490	0.990997	0.984569
77	0.950473	0.982140	0.949299	0.958100	0.988726	0.980522
78	0.941307	0.978111	0.938244	0.949395	0.985944	0.975585
79	0.930816	0.973349	0.925471	0.939377	0.982611	0.969708
80	0.919023	0.967821	0.911009	0.928071	0.978699	0.962857

81	0.905727	0.961377	0.894622	0.915290	0.974090	0.954860
82	0.890766	0.953864	0.876160	0.900897	0.968669	0.945573
83	0.873758	0.944969	0.855273	0.884572	0.962200	0.934722
84	0.854578	0.934496	0.831906	0.865226	0.954532	0.922169
85	0.833367	0.922399	0.806297	0.846008	0.945618	0.907931
86	0.810018	0.908478	0.778395	0.823828	0.935296	0.891857
87	0.783846	0.892089	0.747524	0.799060	0.923055	0.873369
88	0.754456	0.872718	0.713374	0.771343	0.908470	0.852050
89	0.721769	0.850020	0.676024	0.740611	0.891226	0.827689
90	0.685355	0.823326	0.635195	0.706457	0.870735	0.799774
91	0.644398	0.791447	0.590386	0.668154	0.845954	0.767476
92	0.596892	0.751831	0.540043	0.623868	0.814646	0.728876
93	0.541886	0.702560	0.483718	0.572615	0.774898	0.682605
94	0.480873	0.643995	0.423278	0.515535	0.726492	0.629166
95	0.416116	0.577550	0.361101	0.454401	0.669975	0.569725
96	0.349820	0.504901	0.299315	0.390912	0.606039	0.505494
97	0.283816	0.427585	0.239564	0.326423	0.535146	0.437412
98	0.219603	0.346967	0.183059	0.261954	0.457417	0.366077
99	0.160078	0.266685	0.132022	0.199974	0.375108	0.293774
100	0.110715	0.195466	0.090253	0.145974	0.296695	0.226899

TOTAL ATMOSPHERIC TRANSMITTANCE (PATH-CORRECTED)

LEVEL	CHAN 1	CHAN 2	CHAN 3	CHAN 4	CHAN 5	CHAN 6
1	0.991123	0.999640	0.999872	0.999899	0.999927	0.999985
2	0.988599	0.999392	0.999705	0.999767	0.999816	0.999970
3	0.985280	0.999045	0.999485	0.999515	0.999602	0.999933
4	0.980696	0.998526	0.999173	0.999073	0.999220	0.999857
5	0.975207	0.997838	0.998750	0.998485	0.998706	0.999729
6	0.968946	0.996999	0.998194	0.997825	0.998129	0.999543
7	0.961489	0.995951	0.997475	0.997095	0.997501	0.999295
8	0.952409	0.994633	0.996579	0.996305	0.996834	0.998992
9	0.941280	0.992984	0.995477	0.995449	0.996125	0.998631
10	0.927962	0.990948	0.994151	0.994515	0.995356	0.998223
11	0.912467	0.988479	0.992592	0.993497	0.994508	0.997787
12	0.894798	0.985537	0.990779	0.992390	0.993560	0.997325
13	0.875073	0.982071	0.988691	0.991189	0.992497	0.996836
14	0.853544	0.978018	0.986298	0.989880	0.991301	0.996315
15	0.830569	0.973299	0.983554	0.988427	0.989940	0.995750
16	0.806635	0.967841	0.980417	0.986804	0.988397	0.995130
17	0.782254	0.961565	0.976845	0.984995	0.986654	0.994448
18	0.757824	0.954394	0.972786	0.982973	0.984699	0.993697
19	0.733641	0.946252	0.968199	0.980733	0.982529	0.992873
20	0.709827	0.937072	0.963047	0.978268	0.980144	0.991973
21	0.686330	0.926781	0.957293	0.975577	0.977551	0.991000
22	0.662957	0.915307	0.950914	0.972658	0.974753	0.989950
23	0.639437	0.902565	0.943862	0.969483	0.971724	0.988810
24	0.615498	0.888472	0.936119	0.966039	0.968449	0.987580
25	0.590951	0.872951	0.927656	0.962301	0.964909	0.986250
26	0.565674	0.855943	0.918391	0.958227	0.961078	0.984804
27	0.539702	0.837437	0.908280	0.953816	0.956982	0.983241
28	0.513110	0.817422	0.897295	0.949086	0.952663	0.981568
29	0.486019	0.795908	0.885415	0.944054	0.948159	0.979792
30	0.458565	0.772911	0.872623	0.938743	0.943515	0.977917
31	0.430898	0.748469	0.858910	0.933172	0.938775	0.975952
32	0.403163	0.722624	0.844280	0.927363	0.933976	0.973905
33	0.375505	0.695429	0.828747	0.921333	0.929138	0.971791
34	0.348069	0.666944	0.812395	0.915100	0.924278	0.969614
35	0.320999	0.637259	0.795206	0.908677	0.919405	0.967383
36	0.294448	0.606487	0.777159	0.902027	0.914505	0.965107
37	0.268565	0.574790	0.758231	0.895116	0.909567	0.962764
38	0.243488	0.542324	0.738474	0.887957	0.904598	0.960368
39	0.219354	0.509250	0.717938	0.880566	0.899609	0.957930
40	0.196243	0.475728	0.696814	0.873041	0.894641	0.955485

41	0.174290	0.441985	0.675019	0.865296	0.797749	0.953010
42	0.153591	0.408228	0.652599	0.857326	0.884633	0.950512
43	0.134196	0.374654	0.629669	0.849163	0.879594	0.948003
44	0.116190	0.341508	0.606161	0.840715	0.874495	0.945461
45	0.099594	0.308956	0.582299	0.832097	0.869376	0.942924
46	0.084448	0.277221	0.558113	0.823279	0.864220	0.940389
47	0.070776	0.246539	0.533589	0.814191	0.858994	0.937840
48	0.058581	0.217125	0.508783	0.804812	0.853685	0.935272
49	0.047828	0.189178	0.483785	0.795153	0.848290	0.932694
50	0.038468	0.162892	0.458732	0.785227	0.842810	0.930114
51	0.030461	0.138491	0.433634	0.774961	0.837210	0.927513
52	0.023735	0.116153	0.408421	0.764193	0.831424	0.924845
53	0.018176	0.095968	0.383130	0.752833	0.825415	0.922074
54	0.013657	0.078000	0.357879	0.740855	0.819169	0.919185
55	0.010057	0.062309	0.332799	0.728234	0.812670	0.916160
56	0.007251	0.048868	0.308014	0.714949	0.805906	0.912987
57	0.005102	0.037548	0.283658	0.700992	0.798868	0.909650
58	0.003500	0.028213	0.259906	0.686396	0.791560	0.906147
59	0.002329	0.020723	0.236923	0.671196	0.783989	0.902477
60	0.001502	0.014858	0.214790	0.655358	0.776134	0.898614
61	0.000943	0.010375	0.193578	0.638837	0.767968	0.894529
62	0.000575	0.007036	0.173351	0.621560	0.759458	0.890181
63	0.000332	0.004601	0.154180	0.603452	0.750562	0.885520
64	0.000175	0.002913	0.136078	0.584433	0.741219	0.880488
65	0.000080	0.001803	0.119093	0.564389	0.731356	0.875010
66	0.000019	0.001104	0.103241	0.543216	0.720896	0.869005
67	0.000000	0.000659	0.088606	0.520958	0.709821	0.862442
68	0.0	0.000376	0.075280	0.497802	0.698165	0.855326
69	0.0	0.000210	0.063276	0.473828	0.685906	0.847611
70	0.0	0.000117	0.052575	0.449036	0.672989	0.839222
71	0.0	0.000057	0.043169	0.423501	0.659386	0.830082
72	0.0	0.000019	0.035000	0.397390	0.645095	0.820129
73	0.0	0.000000	0.027979	0.370863	0.630102	0.809309
74	0.0	0.0	0.021993	0.343904	0.614297	0.797485
75	0.0	0.0	0.016993	0.316897	0.597764	0.784694
76	0.0	0.0	0.012907	0.290197	0.580587	0.770972
77	0.0	0.0	0.009621	0.263819	0.562664	0.756151
78	0.0	0.0	0.007040	0.238032	0.544031	0.740200
79	0.0	0.0	0.005094	0.213081	0.524729	0.723140
80	0.0	0.0	0.003621	0.189172	0.504789	0.704991

81	0.0	0.0	0.002523	0.166465	0.484202	0.685681
82	0.0	0.0	0.001709	0.145170	0.463007	0.665203
83	0.0	0.0	0.001112	0.125439	0.441255	0.643513
84	0.0	0.0	0.000693	0.107338	0.419025	0.620648
85	0.0	0.0	0.000416	0.090901	0.396407	0.596714
86	0.0	0.0	0.000245	0.076121	0.373451	0.571711
87	0.0	0.0	0.000146	0.062943	0.350085	0.545390
88	0.0	0.0	0.000089	0.051347	0.326309	0.517638
89	0.0	0.0	0.0	0.041315	0.302192	0.488498
90	0.0	0.0	0.0	0.032734	0.277755	0.457873
91	0.0	0.0	0.0	0.025489	0.252999	0.425604
92	0.0	0.0	0.0	0.019426	0.227658	0.391003
93	0.0	0.0	0.0	0.014421	0.201631	0.353738
94	0.0	0.0	0.0	0.010399	0.175348	0.314507
95	0.0	0.0	0.0	0.007269	0.149394	0.274293
96	0.0	0.0	0.0	0.004913	0.124323	0.234018
97	0.0	0.0	0.0	0.003195	0.100556	0.194395
98	0.0	0.0	0.0	0.001984	0.078375	0.155909
99	0.0	0.0	0.0	0.001167	0.058336	0.119676
100	0.0	0.0	0.0	0.000653	0.041607	0.088149

STATION NUMBER 1
ZENITH ANGLE = 0.5
STATION LATITUDE = 28.50
STANDARD ATMOSPHERE TEMPERATURE ADJUSTMENT = -1.35

THE TEMPERATURE PROFILE CONVERGED AFTER 5 ITERATIONS

	PRESSURE	TEMP.	SOUNDING	ERROR	NESS	NESS-ERROR
1	1000.000	19.040	17.800	1.240	19.500	1.700
2	850.000	9.258	8.200	1.058	12.200	4.000
3	700.000	0.673	2.400	-1.727	4.200	1.800
4	500.000	-15.343	-11.900	-3.442	-12.500	-0.600
5	400.000	-26.558	-23.700	-2.858	-24.800	-1.100
6	300.000	-41.024	-37.800	-3.224	-40.000	-2.200
7	250.000	-50.042	-50.500	0.458	-49.200	1.300
8	200.000	-59.096	-50.100	-8.996	-58.400	-8.300
9	150.000	-63.405	-59.200	-4.205	-63.200	-4.000
10	100.000	-69.225	-67.300	-1.925	-69.900	-2.600
11	70.000	-66.896	-69.500	2.604	-68.300	1.200
12	50.000	-61.774	-62.200	0.426	-63.400	-1.200
13	30.000	-55.185	-55.300	0.115	-56.900	-1.600
14	20.000	-47.887	-51.300	3.413	-50.900	0.400
15	10.000	-40.474	-36.500	-3.974	-42.000	-5.500

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Test and evaluation
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column NOAA 2 radiances.